EVERYDAY USES OF PORTLAND CEMENT

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EVERYDAY USES OF PORTLAND CEMENT

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EVERYDAY USES OF PORTLAND CEMENT

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THE CEMENT MARKETING COMPANY LIMITED
Selling Organisation of
The Associated Portland Cement Manufacturers Ltd.
The British Portland Cement Manufacturers Ltd.
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PREFACE

Since it was first issued in 1909, "Everyday Uses of Portland Cement" has passed through four editions, totalling no less than 35,000 copies. Each of these editions at intervals of a few years recorded progressive stages in the extended uses of concrete and reinforced concrete, but a comparison of the present fifth edition with that last issued in 1921 shows that in the past nine years tremendous strides have been made in every direction in the use of concrete. Not only have the older types of concrete construction been developed, but innumerable new uses have been discovered for Portland cement and Portland cement concrete.

In this volume an endeavour has been made to present in a practical manner the essential factors for the production of good concrete and methods of using it to the best advantage. No attempt is made to teach reinforced concrete design; nor is it possible to deal at great length with any one subject, or to go into such details as might have been included in a text-book on each of the subjects covered; the object is rather to give as much information of practical value to cement users as is possible within the pages of one book.

The book is divided into nine Sections, dealing respectively with Materials; Workmanship; Surface Treatment; Practice; Roads; Houses, Bungalows, Garages and Farm Buildings; Cast Stone; Concrete Products; and Theory of Reinforced Concrete. Each section is prefaced by a list of its contents, while a general index is given at the end of the book.

It is hoped that this book will be of real value to all users of our "Blue Circle" Portland cement, "Ferrocrete" rapid-hardening Portland cement, "Snowcrete" white Portland cement, "Colorcrete" coloured Portland cement, and "Lightning" brand aluminous cement. It may be pointed out that "Ferrocrete" was the first rapid-hardening Portland cement made in Great Britain, that "Lightning" brand was the first aluminous cement made here, and that "Snowcrete" is the first white Portland cement made in this country, a record of successful pioneer work of which we are justly proud.

Our organisation making and selling these cements is the largest cement manufacturing concern in Great Britain, and all users can be certain in purchasing cements bearing these trade names that they are obtaining the highest quality cements made anywhere in the world.

The Cement Marketing Company Limited at this address has the most up-to-date cement and concrete testing Laboratory in the world and a staff of experienced engineers ; these are freely at the disposal of our customers.

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FAMOUS BRANDS OF PORTLAND CEMENT
MARKETED BY
THE CEMENT MARKETING COMPANY LTD.

PORTLAND
BLUE
CIRCLE
CEMENT

"FERROCRETE"
THE RAPID HARDENING
PORTLAND CEMENT

WHITE
"SNOWCRETE"
PORTLAND CEMENT

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INTRODUCTION AND HISTORICAL NOTE

Although the use of cementing materials in building construction dates from the very earliest times, the Portland cement we know to-day is a comparatively modern material. Lime mortar was the cementing material used by the Egyptians in the construction of the Pyramids, by the Ancient Greeks, and by the Romans ; it was the most common cementing material in use from those early times right through to the early part of the nineteenth century when, in 1824, James Aspdin patented a material which he called " Portland cement " because of its likeness, when hardened, to Portland stone. During the following few years Aspdin and others working along the same lines made every endeavour to keep their processes as secret as possible, and little progress was made. The material was, however, in those days used for some important works, including Brunel's Thames Tunnel in 1838 ; Trinity House Corporation Buildings, by James Walker (then President of the Society of Civil Engineers), in 1842 ; and early railway works by Sir C. W. Pasley (Inspector-General of Railways) and Robert Stephenson in 1842–3. At the General Exhibition held in Hyde Park in 1851 public interest in a number of tests carried out on Portland cement gave a great impetus to the industry, and in 1859 John Grant, then Engineer to the Metropolitan Board of Works, decided to use the material in the construction of the London Drainage System.

During this period a number of factories were started for the manufacture of Portland cement. Many of these early firms, such as J. B. White & Brothers, Brooks, Shoobridge & Co., Francis & Co., Hilton, Anderson & Co., and others are now incorporated in or associated with the Associated Portland Cement Manufacturers, Ltd., and the British Portland-Cement Manufacturers, Ltd., whose joint selling organisation is the Cement Marketing Co., Ltd. Until the introduction by the Cement Marketing Co., Ltd., a few years ago, of the trade name " Blue Circle " to cover the ordinary Portland cements manufactured by these allied companies, many of the old trade names were still in use. In fact in some districts cement is still ordered by these famous old trade names, while abroad they remain in common use.

It is an interesting fact that the successors of these firms established upwards of a century ago have kept abreast of the times and are now in the forefront with their developments of " Ferrocrete "—the pioneer rapid-hardening Portland cement; "Lightning"—the first aluminous cement manufactured in Great Britain; "Snowcrete"—the first, and at the time of writing the only, white Portland cement made in Great Britain; and "Colorcrete."

The enormous improvements made in Portland cement manufacture in recent years are graphically shown in the chart on p. 5, from which it will be seen that the tensile strength of ordinary Portland cement (neat) has increased from 302 lbs. per square inch in 1862 to 533 lbs. in 1891, 850 lbs. in 1924, and 1050 lbs. in 1929; the last two figures relate to "Blue Circle" Portland cement.

A notable step forward was made in 1924, when "Ferrocrete" rapid-hardening Portland cement was produced by the Associated Companies. "Ferrocrete" has revolutionised ideas on the speed and strength of concrete construction, and while the subject is dealt with fully in Part I of this book it may here be stated that the 1 cement : 3 sand tensile strength of "Ferrocrete" at 28 days is over 700 lbs. per square inch; in 4 days "Ferrocrete" has the same strength as concrete made with ordinary Portland cement at 28 days, while its strength at all later ages is considerably greater. It is a source of satisfaction that this great improvement in Portland cement has been developed in Great Britain to a stage of quality beyond the continental rapid-hardening Portland cements. England is the home of Portland cement: it was invented here, and most of the notable improvements in both the quality of the material and manufacturing processes have been the result of English investigations. For half a century England supplied the bulk of the Portland cement used throughout the world. Other countries have now, of course, established cement industries of their own, some of them exceeding England in the tonnage produced, but the supremacy of the English product is acknowledged throughout the world, and the Associated Companies do a very large export trade to all parts of the world.

The improvement in the quality and strength of Portland cement in recent years has coincided with great developments in the use of Portland cement concrete. This has been due in part to a realisation of the many uses for a cheap and durable material which is enormously strong in compression, which can be made on the site where it is to be used, and which can be easily placed in position. The discovery in the latter part of the nineteenth century that the incorporation of steel in concrete resulted in a composite material, reinforced concrete, which is strong in both compression and tension, has, however, been chiefly responsible for the consumption of Portland cement increasing so rapidly.

It is only about thirty years since the first reinforced concrete structure was erected in this country, yet already it takes its place in the front rank of building materials. For many types of structure, particularly industrial structures, bridges, marine structures, roads and road foundations, reinforced concrete is recognised as the most suitable and at the same time the cheapest material. Engineers early realised the possibilities of the new material at their disposal. Architects, too, soon realised that reinforced concrete had come to stay, and now architectural design in reinforced concrete is taught in most architectural schools. The result is to be seen on every hand. Fine bridges, monumental buildings, dignified factory and warehouse buildings, attractive houses, all built in plain or reinforced concrete, are to be seen throughout the country. It is perhaps too early to say that reinforced concrete has developed a style of its own, but there is a distinct tendency in this direction as will be seen from the many notable reinforced concrete structures by leading architects illustrated in the following pages.

Rapid strides have also been made with the surface treatment of concrete. For architectural purposes there are available every natural stone finish, pure white surfaces, or the variegated shades of the aggregate of which the concrete is made, while Portland cement can be coloured to any desired shade by the addition of suitable colouring materials ; the surface may be as smooth as glass, or of practically any degree of roughness. And all these are obtained without imitation or artifice, simply by the use of different methods of treating concrete as concrete.

Apart from its architectural possibilities the inherent advantages of reinforced concrete include :

(1) Cheapness in first cost.
(2) Rapidity of construction.
(3) Economy in maintenance.
(4) Strength.
(5) Durability.
(6) Fire resistance.
(7) Hygienic qualities.
(8) Plasticity.

The initial economy of concrete is due to the fact that a supply of suitable aggregate is available in almost every part of the country, and that a great deal of unskilled and semi-skilled labour may be used in its manufacture.

In many cases an architect or engineer will know without question that reinforced concrete is the cheapest, or the only possible, material for contemplated works, but it is always advisable to ascertain the cost in reinforced concrete even if other materials are generally used. It must always be borne in mind that concrete grows stronger with age, and does not deteriorate ; neither does it need painting at short intervals, which is such an expensive item with some other materials ; it does not even need occasionally pointing as does brickwork in lime mortar.

The monolithic nature of reinforced concrete is of great importance, especially in districts liable to subsidence or earthquake shocks. In this type of construction the walls, floors, and roof may be designed as one monolithic whole, so that in case of subsidence the building does not collapse.

This is strikingly demonstrated in the illustrations on pp. 34 and 38, which show very large structures which, when the soil moved beneath them, simply tilted over and were returned later to their original position at a comparatively small cost.

Concrete buildings are the most fire-resisting of all structures, and even in steel-frame structures concrete is generally used as a casing to protect the steel. There are many instances on record (and some are illustrated later) of composite buildings of reinforced concrete and steel in which fire has totally destroyed the whole of the structure except those parts in reinforced concrete.

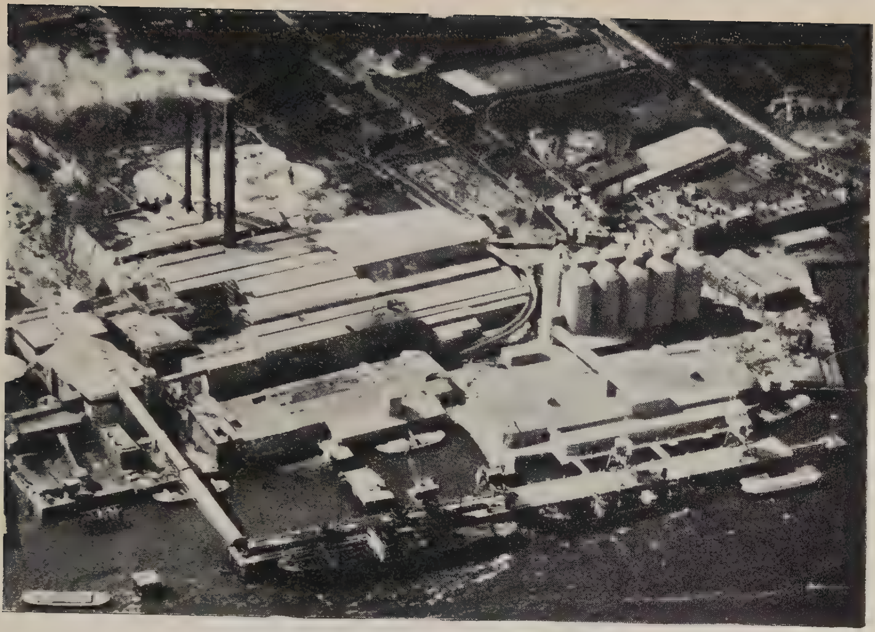
This Introduction would not be complete without a reference to the enormous growth of small pre-cast concrete units and cast stone. The manufacture of concrete paving flags, kerb, fence posts, pipes, blocks, slabs, bricks, roofing tiles, garden ornaments, etc., has now reached the proportions of a large industry giving employment to thousands of men, while the progress in the manufacture of cast stone for architectural use has been such that there are at least half a million cubic feet used in London alone each year.

Another direction in which very large quantities of cement are used is in the construction of roads. For all roads carrying heavy vehicular traffic a concrete foundation is a necessity. For roads carrying less traffic reinforced concrete is also actually cheaper in first cost than other materials, and this, together with economies in maintenance, is the explanation of the large number of concrete secondary roads in rural districts and carriageways now under construction on housing estates. The total mileage of all-concrete roads in Great Britain has increased by about 200 per cent. in the past two years, and is now about 1,000 miles.

Portland cement now enters more largely into our lives than most people suspect: in the construction of the roads and pavements on which we walk, the buildings in which we work, the houses we live in, the decoration of parks and gardens, and in many other directions concrete is becoming more and more essential, due to its low cost, strength and durability and the ease with which it can be moulded to any desired shape. New uses for cement are being discovered almost every day.

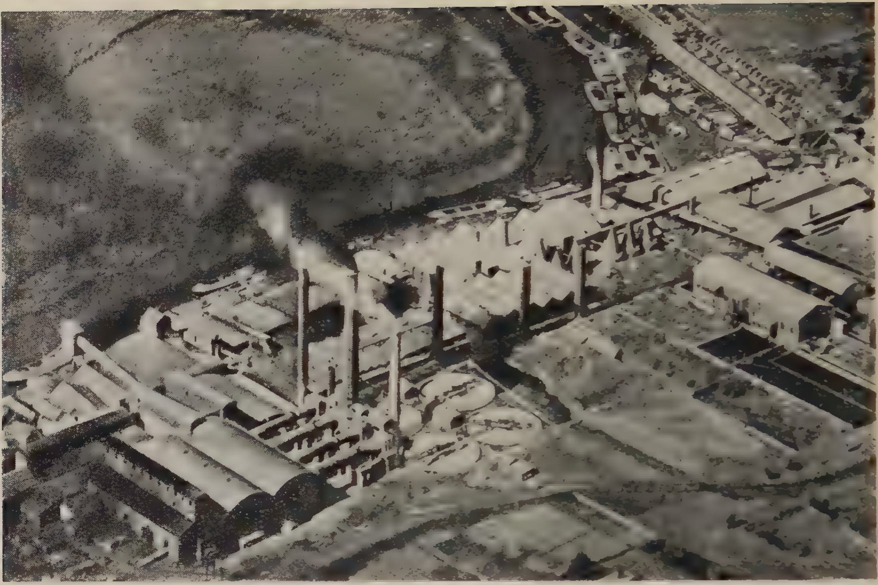
On the following seven pages are given photographs of a few of the cement works of the Associated Companies, which produce the bulk of the cement manufactured in Great Britain, and are conveniently situated for delivery in any part of the country.

The aeroplane views are by Aerofilms, Ltd., and Surrey Flying Services.

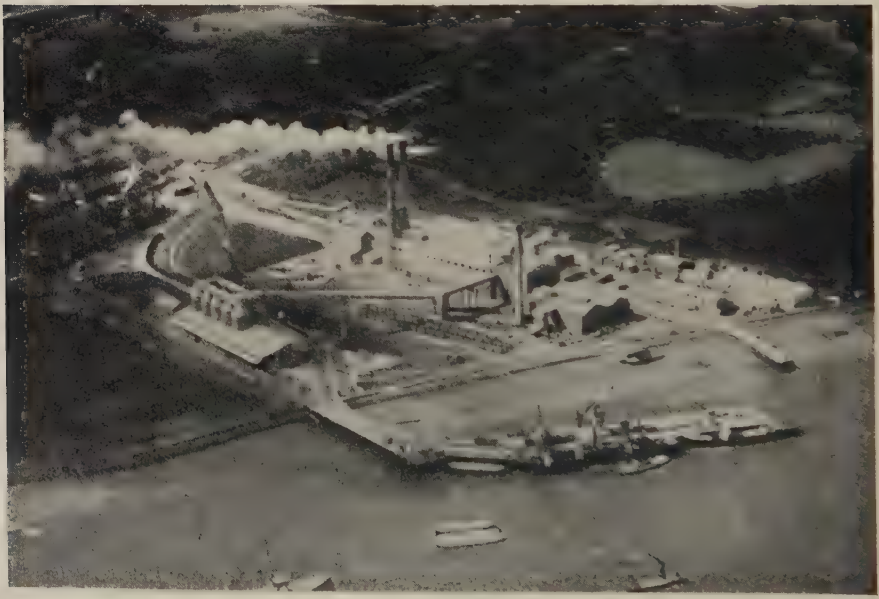


Bevans Works, Northfleet, Kent.

Swanscombe Works, Swanscombe, Kent.

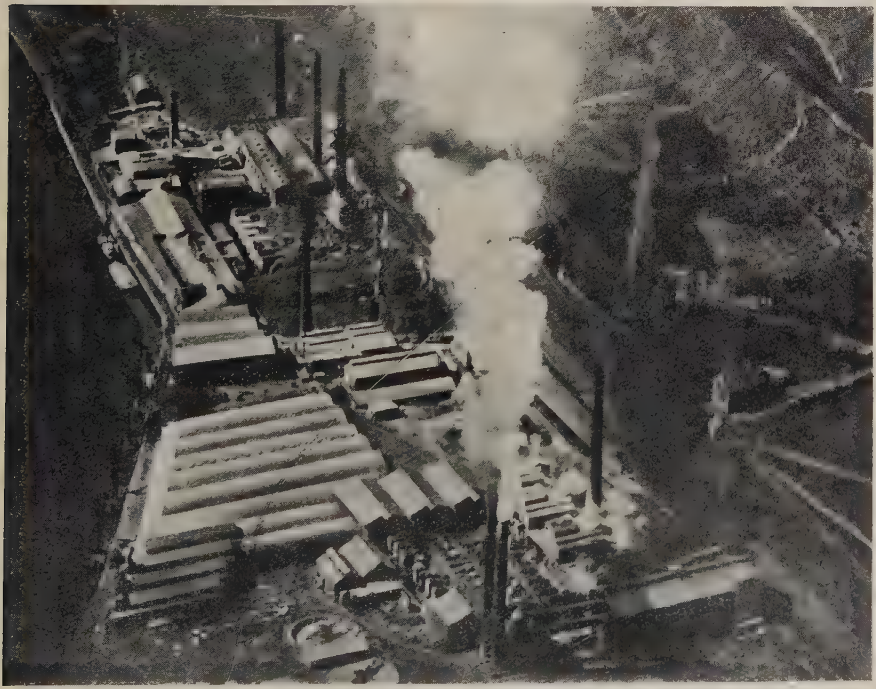


Burham Works, near Maidstone, Kent.



Kent Works, Dartford, Kent.

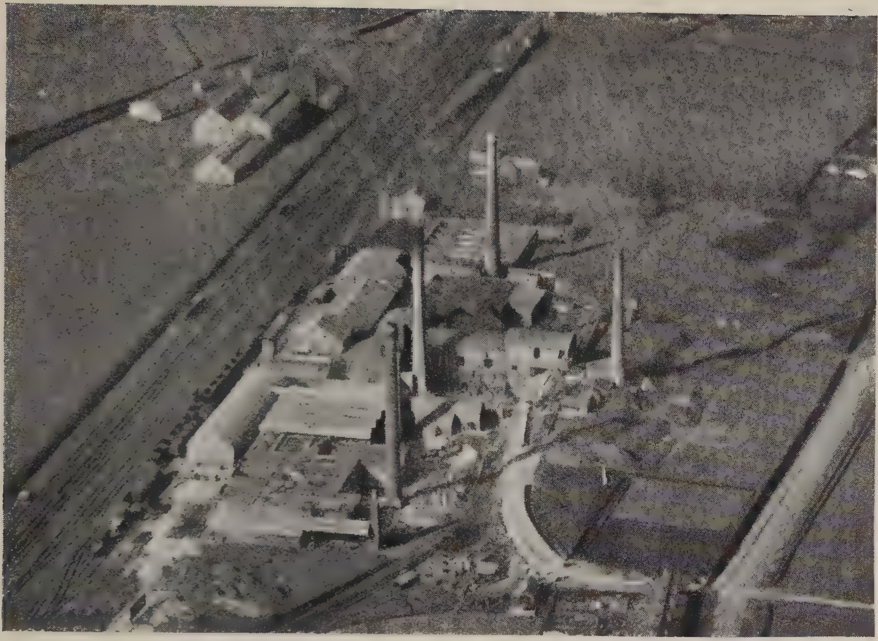
Wouldham Works, Grays, Essex.



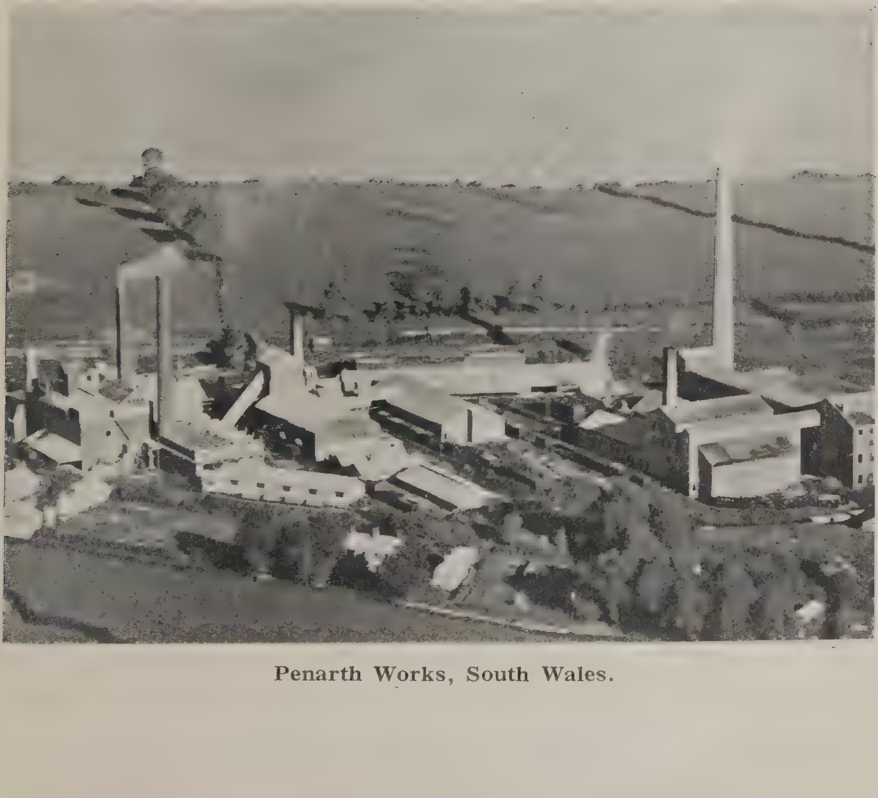
Martin Earles Works, near Rochester, Kent.

Shoreham Works, Sussex.

Norman Works, Cambridge.

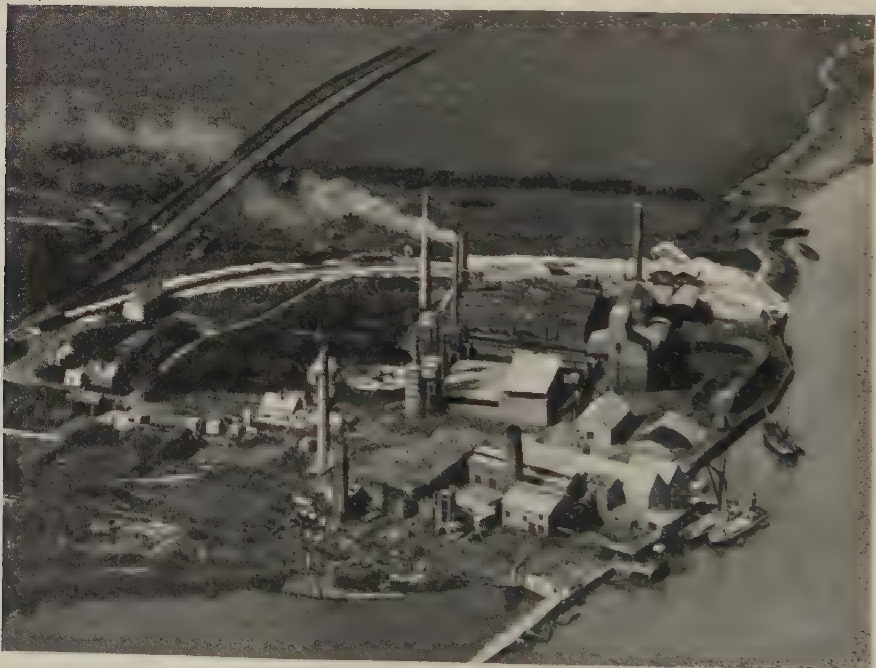


Arlesey Works, near Dunstable, Bedfordshire.



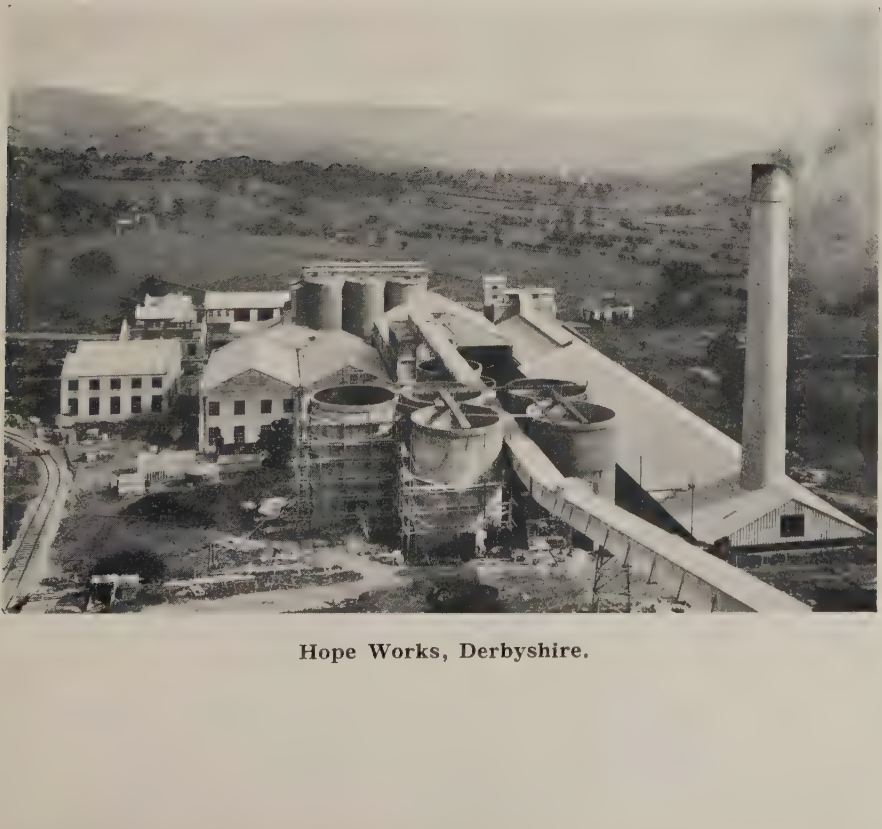
Penarth Works, South Wales.

Sundon Works, near Luton, Bedfordshire.



Vectis Works, Isle of Wight.

Magheramorne Works, Larne, Ireland.



Hope Works, Derbyshire.

PART I

MATERIALS

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MATERIALS

PORTLAND CEMENT

Great Britain is essentially the home of the Portland cement industry, for the material was invented by James Aspdin, a Leeds bricklayer, in 1824, and practically every improvement in quality and manufacturing processes has been developed in this country. Portland cement was so named because when set it resembles Portland stone in colour. The world's production to-day is about 90,000,000 tons a year, of which the United States and Europe are each responsible for about one-third.

In most of the countries in which Portland cement is manufactured to any extent it is controlled by a standard specification. In Great Britain this specification is issued by the British Engineering Standards Association, and all cement should be ordered on the understanding that it complies with this specification, particularly as foreign specifications do not all call for the same high quality. Foreign Portland cements, although they may comply with the specifications in force in their country of origin, may not give the same results as a British Portland cement complying with the British Standard Specification : moreover, all foreign cements are not artificial Portland cements.

The British Standard Specification for Portland cement, last revised in 1925, includes the following principal requirements :

Maximum Residue on	
180 × 180 sieve	10 per cent.
76 × 76 „	1 „ „
Chemical Composition—	
$\frac{CaO}{SiO_2 + Al_2O_3}$ Molecular limits .	2·0 to 2·9
Insoluble residue, maximum . .	1·5 per cent.
Magnesia „ . .	4 „ „
Sulphur (as SO_3) „ . .	2·75 „ „
Loss on ignition „ . .	3 „ „
Tensile Strength—	
7 days neat, minimum . . .	600 lbs. per sq. in.
7 days—3 sand, 1 cement, minimum	325 lbs. per sq. in.
28 „ „ „ „	$7 \text{ days result} + \frac{10,000}{7 \text{ days result}}$

Setting Time—

Initial set, minimum . . .	30 minutes.
Final set, maximum . . .	10 hours.

Soundness—

Le Chatelier test, maximum . .	10 mm.

All cement supplied by the Cement Marketing Company Ltd. is guaranteed to be far in excess of these requirements. The tensile strengths of "Blue Circle" Portland cement, mixed in the proportions of one part of cement to three parts of standard sand, and at various periods after gauging are given in Table 1 (page 17). It will be observed that the strength of "Blue Circle" cement at 7 days is 69 per cent. greater than the value required to comply with the British Standard Specification. The remarkable increase in the strength of Portland cement in recent years due to improved methods of manufacture is shown in *Fig.* 1.

The Cement Marketing Co. Ltd. controls the largest group of cement factories in Great Britain, including the largest cement factory in Europe (Bevans Works at Northfleet) with an output of 10,000 tons a week. Some of these factories are illustrated in this section.

Raw Materials.—Most of the Portland cement in England is made by mixing chalk, or limestone and clay with water into a creamy liquid called "slurry," which is put into a kiln, where it is heated until it dries and ultimately becomes white hot, and then grinding the "clinker"—as the material is called after it has passed through the kiln—to a fine powder.

In chemical terms, the essential raw materials are (1) calcareous, or material containing lime; and (2) argillaceous, or clayey material. Chalk is carbonate of lime, and another form of this is limestone, which is equally suitable for cement manufacture and largely used in other countries where chalk does not exist. Clay is the argillaceous raw material usually employed, but another form is shale, which is chemically similar but has become baked or hardened on the earth's crust.

The first stage in cement manufacture is to grind the raw materials to a fine state, and the softer the raw materials are the easier it is to grind them. Chalk is the softest calcareous material, and hence the bulk of the cement made in England is produced from chalk and clay. This is the reason the centre of the cement industry is on the banks of the Thames and Medway, where there are vast deposits of chalk and clay.

Excavating Raw Materials.—At the majority of cement works using chalk or chalk marl, the chalk is dug from the cliff with steam or electric navvies, the more modern being equipped with caterpillar wheels to enable the machines to travel quickly and conveniently along the foot of the cliff (see *Fig.* 2). Such mechanical navvies with buckets of three-yards capacity will dig 100 tons of chalk per hour with only two or three men in attendance.

The chalk is usually deposited by the navvy buckets into railway wagons of ten tons capacity and then hauled to the wash-mills by locomotive for the first process of manufacture (*Fig.* 4).

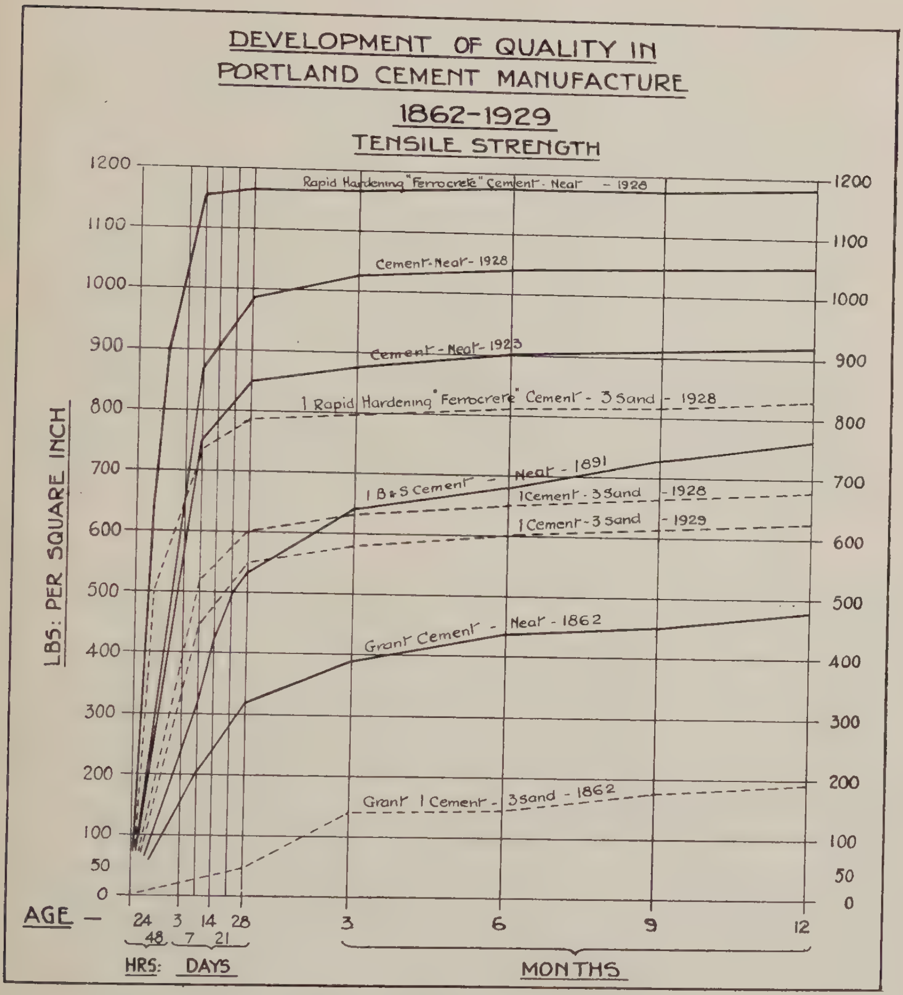


Fig. 1.

In the case of limestone workings it is necessary to loosen and shatter the rock by blasting.

When clay is used in cement manufacture it is dug by a steam or electric navvy, a crane fitted with a grab (*Fig.* 3), or buckets on a travelling chain or belt. The clay marshes on the Thames and Medway estuaries,

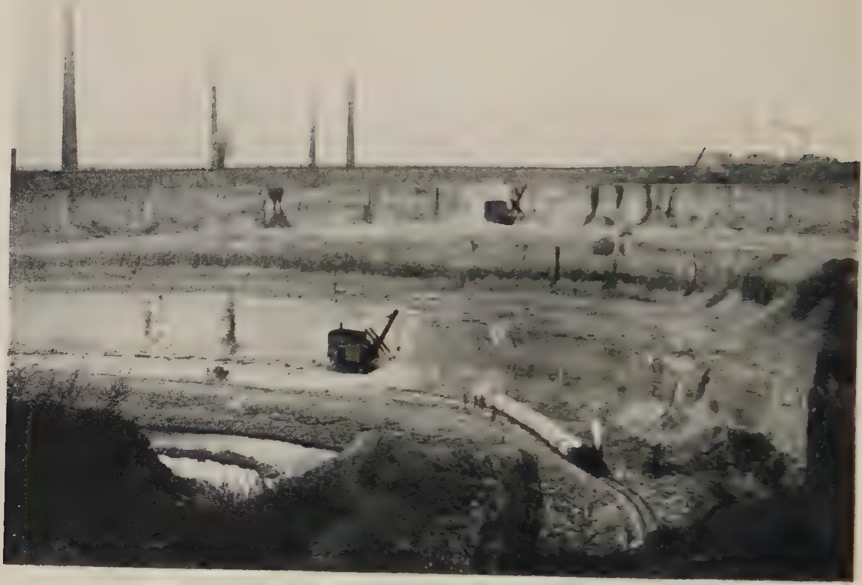


Fig. 2.—Excavating Chalk.

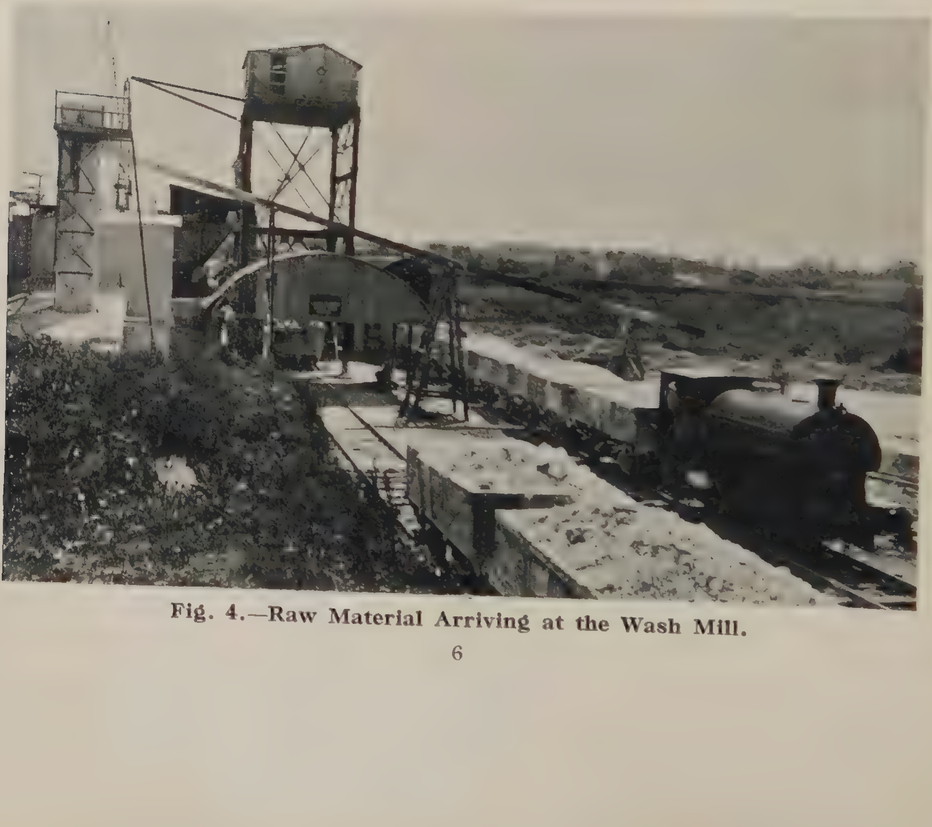


Fig. 4.—Raw Material Arriving at the Wash Mill.

which have furnished millions of tons of "river mud" for cement manufacture, are particularly suitable for working by grab cranes on floating decks. Useless material, such as loam or gravel, which lies above the chalk or limestone must be removed before the working of the chalk or limestone can be begun.

Raw Material Preparation.—The first process of cement manufacture is to grind the raw materials to a very fine state of division and to mix them to a chemical composition as nearly constant as can be obtained.

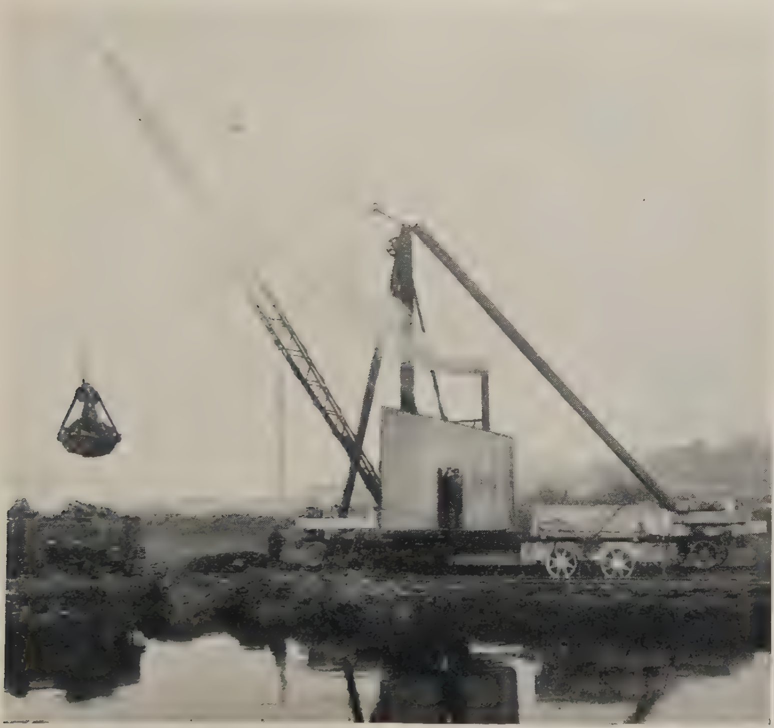


Fig. 3.—Digging Clay in Marshland.

In the case of chalk and clay the materials are in definite proportions, tipped together with a stream of water into washmills (*Fig.* 5), usually excavated in the ground, about 20 ft. in diameter and 6 ft. deep, in which a rotating vertical spindle carries a horizontal steel framework to which are suspended heavy harrows fitted with projecting teeth, or "tines." The circumference of the washmills is fitted with gratings or screens, and the process consists of breaking up the lumps of chalk and clay by means of the rotating harrows and "tines" until a creamy liquid known as slurry, which is able to pass through the screens, is formed. The usual procedure is for the slurry to pass through a series of two or three wash-mills each in turn having finer screens than the preceding one, so that the final product is composed of a mixture of very fine particles of chalk and clay with just sufficient water to enable it to flow. It is usual for the washmill process to be continued until the slurry contains less than 5 per cent. of residue on a sieve having 32,400 meshes to the square inch.

Crushing.—Some of the raw materials, for example limestone, used for making cement are too hard to be broken up in washmills, and in such cases are usually first crushed to reduce the lumps to 1½ inches down to powder. The crushed stone then passes to tube mills with a stream of water for final reduction to slurry. Tube mills consist of cylinders from 20 to 40 ft. long and 5 to 7 ft. in diameter revolving at a speed of 20 to 30 revolutions per minute on a horizontal axis. The mills are charged to about 40 per cent. of their volume with iron balls, and it is the cascading of these balls within the mill, caused by rotation, which grinds the crushed stone in the presence of water to an impalpable cream.

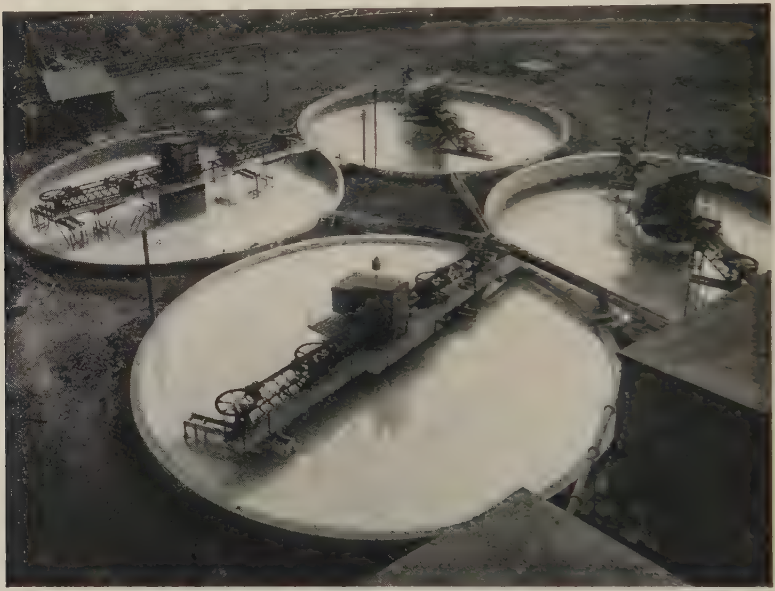


Fig. 5.—Slurry Tanks.

Whereas chalk and clay can be converted into slurry in washmills for no more than 7 h.p. per ton, it may need as much as 30 h.p. per ton of limestone and shale to produce slurry.

Slurry Testing.—Chemists decide, after chemical analyses, what proportions of chalk and clay are to be tipped into the washmills, and of limestone and shale to the crushers. By hourly tests of the slurry flowing from the mills they ascertain whether the chemical composition is right, and if not make the necessary adjustments. The fineness of the grinding of the slurry also comes under the chemists' supervision, and frequent tests are made by sieving definite weights of slurry on sieves with 32,400 meshes to the square inch to make certain that there is no more than about 5 per cent. of residue. Unless the slurry is of the right composition and finely ground it is impossible to produce high-quality cement.

Slurry Mixing.—After the slurry has been ground to the necessary degree of fineness, it passes to mixers for the purpose of making the chemical composition as even as possible. This is an essential part of the cement manufacturing process, because if the proportion of carbonate of lime in the slurry varies by as little as 1 part in 200 from that decided upon as correct the quality of the cement will be injured. In a well-equipped works the slurry is not passed by the chemists as satisfactory until it has been so mixed that the percentage of carbonate of lime is within 0·2 per cent. of that required.

The mixing is done either mechanically by stirring and circulation, or by air-agitation, i.e. by bubbling air through a large depth of slurry to cause circulation. Mechanical mixers are large basins about 60 ft. in diameter and 10 ft. deep in which there are revolving arms, and this stirring in a horizontal direction is supplemented by pumping the supply for the kilns from the bottom of the mixers and returning the overflow or surplus slurry to the top. Air-agitated mixers are usually above ground and compressed air is blown in through valves in the bottom of the tank.

Wet and Dry Processes.—Raw material preparation is of the utmost importance in cement manufacture, and good quality cement cannot be obtained unless this part of the process is well done. Although nearly all the cement made in this country is made by the wet process method of raw material preparation described, the dry process is occasionally adopted here and more extensively in other countries, where the raw materials are generally harder.

The dry process may be of advantage where the raw materials contain only a small proportion of water, say, up to 10 per cent., but not with raw material like chalk and clay which may contain 15 per cent. and 25 per cent. respectively of water. In the dry process the raw materials after quarrying are crushed and then passed through drying drums, which are steel cylinders from 40 to 100 ft. long and from 4 to 6 ft. diameter, slightly inclined to the horizontal. These cylinders are slowly rotated on their axes, and the raw materials flow gradually through them, meeting at the same time a flow of hot flue gas from a special furnace, or waste gas from a cement kiln. The dried raw materials on leaving the drying drums go to grinding mills, usually of the tube mill type, where they are reduced to a fine powder.

Mixing, which is not easy on the dry process, takes place to some extent by feeding the two raw materials to the mills in weighed quantities in the required proportions, but this is also supplemented by storing large quantities —sufficient for two or three weeks' manufacture—of the ground raw materials in silos and mixing the powder by circulation, i.e. by extracting from the bottom of two or more silos at one time and discharging the combination into another silo.

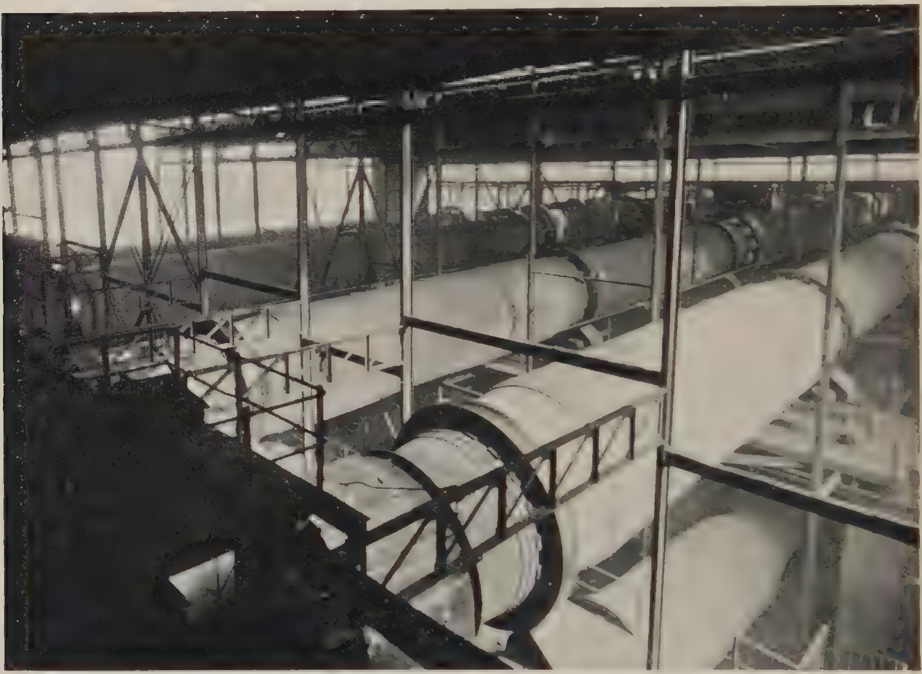


Fig. 6.—The Kilns at Bevans Works, Northfleet.

Calcining.—Cement "burning" or calcining consists of heating either the slurry or dry raw material mixture to a white heat to effect the necessary chemical combination to make cement. Burning, with few exceptions, takes place nowadays in rotary kilns (*Fig.* 6), which are brick-lined steel-plate cylinders from 100 to 400 ft. long and from 6 to 12 ft. in diameter, according to the output required.

A small rotary kiln, 100 ft. long and 6 ft. diameter, will make 350 tons of cement clinker a week, and the largest kilns produce over 2,500 tons a week each. These huge cylinders are mounted on rollers arranged to make the cylinder slightly inclined to the horizontal, so that as the slurry enters at the higher end of the kiln it gradually passes down the kiln as the latter revolves. At the lower end of the kiln a flame of powdered coal creates an extremely hot furnace, from which the products of combustion pass through the kiln and leave at the upper end where the slurry enters.

On its passage through the kiln, lasting three or four hours, the slurry is dried and heated finally to a temperature which approaches 2,800 deg. F. The cement material takes the form of nodules ranging in size from $\frac{1}{8}$-in. to $\frac{1}{2}$-in. diameter, and there is a constant stream of these white, hot nodules issuing from the kiln.

The flame of powdered coal that generates and maintains the heat in the burning zone of the kiln is produced by blowing ground dry coal through a pipe with a fan blast. The coal, on leaving the pipe, ignites immediately.

In the rotary kiln take place the chemical changes that convert a mixture of chalk or limestone and clay or shale into cement compounds. About one-third of the length of the rotary kiln is occupied in drying the slurry. One half is required to raise the temperature of the dried slurry to about 1,500 deg. F. and to maintain that temperature while the carbonate of lime is changed into caustic lime. The remaining one-sixth of the length of the kiln, which is the zone of maximum temperature, serves to effect the chemical combination between lime and silica, and lime and alumina, to form silicates of lime and aluminates of lime, which are the essential constituents of cement, giving it its qualities of setting and hardening. The cement burning operation requires 6 or 7 cwts. of coal per ton of cement.

The cement clinker on leaving the rotary kiln is white hot, and for cooling purposes it is allowed to flow into another rotating drum about one-third the length of the rotary kiln and two-thirds its diameter, or into a number of much smaller drums arranged around the firing end of the kiln. While the clinker is slowly passing through this drum it meets a current of air passing in the opposite direction on its way to the kiln, this being the air required for combustion. The result is that the air gets heated to about 600 deg. F. and the clinker is cooled. The heating in this way of the air for combustion constitutes a recovery of heat that would otherwise be wasted.

Grinding.—The last stage in the process of manufacture of Portland cement is the grinding of the clinker to a fine powder. This is usually done in compound tube mills, which are cylinders about 30 ft. long and 6 or 7 ft. diameter rotating on a horizontal axis (*Fig.* 7). The cylinders are divided into three or four compartments by slotted diaphrams, the first compartment containing about one-third of its volume of 3-in. or 4-in. diameter steel balls, the next compartment containing balls of about 2 in.

diameter, and the finishing compartment being charged with balls or pellets of about 1 in. diameter and less.

The clinker passes in succession through these three chambers and is gradually reduced to an extremely fine powder which flows through the end of the mill. A small proportion (about 2 or 3 per cent.) of gypsum is ground with the clinker in order to make the cement slow setting.

Although tube-mill grinding is very simple in principle, it is a costly operation, because about 50 h.p. hours per ton of cement are required, and the wear and tear on the tube-mill lining (cast iron or steel plates) arising from the continuous rotation at a speed of 20 or 25 revolutions per minute of about 20 tons of iron or steel balls is extremely heavy.

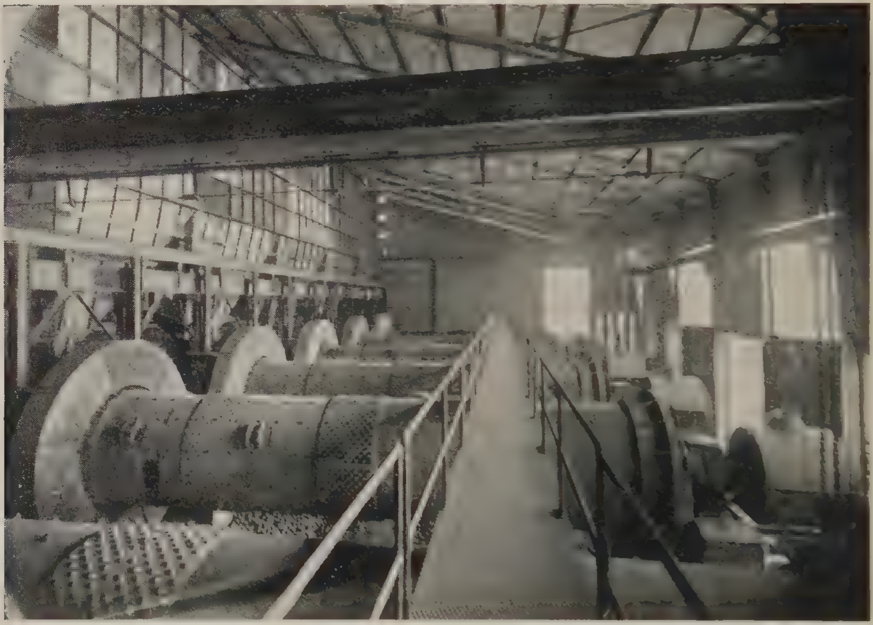


Fig. 7.—Cement Grinding Mills.

After grinding, the cement is transported either by elevators and conveyors, or by air pressure, into large concrete silos holding about 3,000 tons of cement each (*Figs.* 8 and 9), or into sheds where the cement accumulates into heaps 10 ft. to 15 ft. deep.

Fineness.—Cement is usually ground so finely that the residue on the sieve of 32,400 meshes per square inch does not exceed 5 per cent., but for rapid-hardening cement, which will be described later, the fineness of

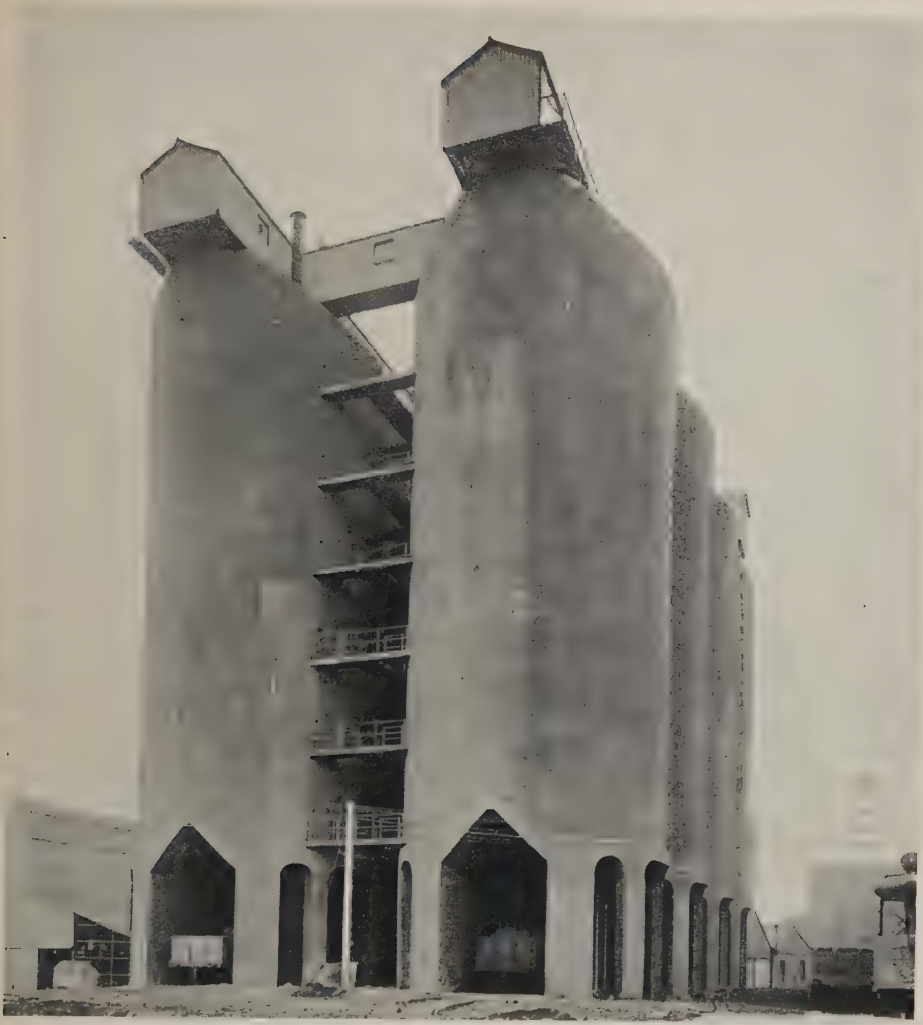


Fig. 8.—Cement Silos showing Railway Tunnels at Johnson's Works.

grinding is such that less than ten of one per cent. of residue is left on such a sieve.

Testing.—At a works where proper attention is given to all the processes of manufacture the final quality of cement is automatically controlled, but it is never the custom to assume that this is so, and each day's output of cement is tested for all its qualities before it is despatched.

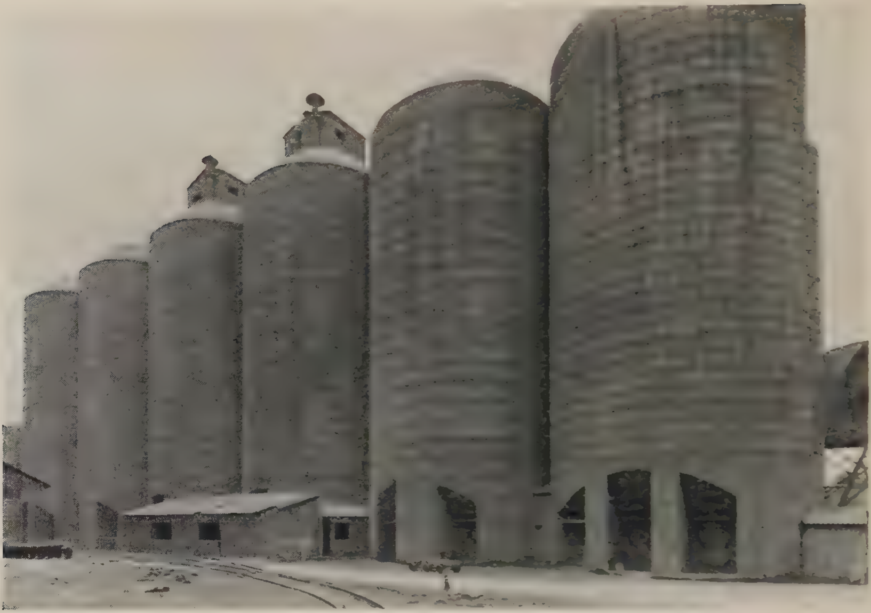
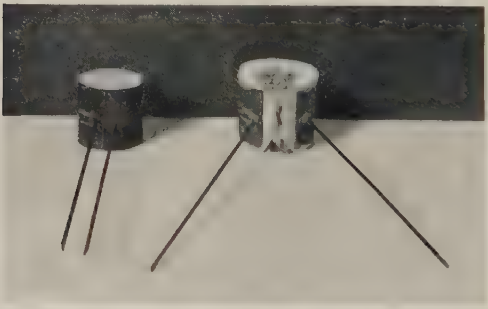


Fig. 9.—Silos at Bevans Works.

Soundness Test.—The fundamental requirements of a cement are that it should be sound, i.e. free from expansion after it has set, of suitable setting time, and strong. The soundness is determined by the Le Chatelier test (*Fig.* 10), which consists of boiling for 6 hours a small cylinder of the cement and



Sound. Unsound.

Fig. 10.—Soundness Test.

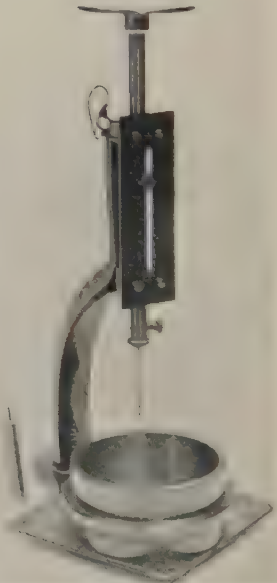


Fig. 11.—Setting-time Test.

measuring the expansion by means of indicator needles which magnify the movement to a considerable degree. The British Standard Specification requires that the movement at the end of the needles after boiling should not exceed 10 mm., and if this requirement is complied with there is perfect security that the cement in question will not expand with age.

Setting-time Test.—The setting-time must be within reasonable limits, first to ensure that the cement does not set before the concrete has been properly mixed and placed in its final position; and, second, to ensure that the cement will set within a few hours and not be so slow setting as to delay the work in which it is employed. Hence the British Standard Specification puts the limit of setting time between 30 minutes and 10 hours. The setting time is determined by observing the penetration of a needle, weighted to about half-a-pound, into a small block of the cement (*Fig.* 11).

Fig. 12.—Deep-Water Jetty at Bevans Works.

Strength Test.—The strength upon which the quality of cement is judged is in tension, and this test is carried out in testing machines (*Figs.* 15 and 16) on briquettes having a minimum section of 1 sq. in. made both with neat cement and cement mixed with three parts of standard sand which has a definite size of grain. The strength is tested usually at 7 days and 28 days. The British Standard Specification requires that the 7 days'

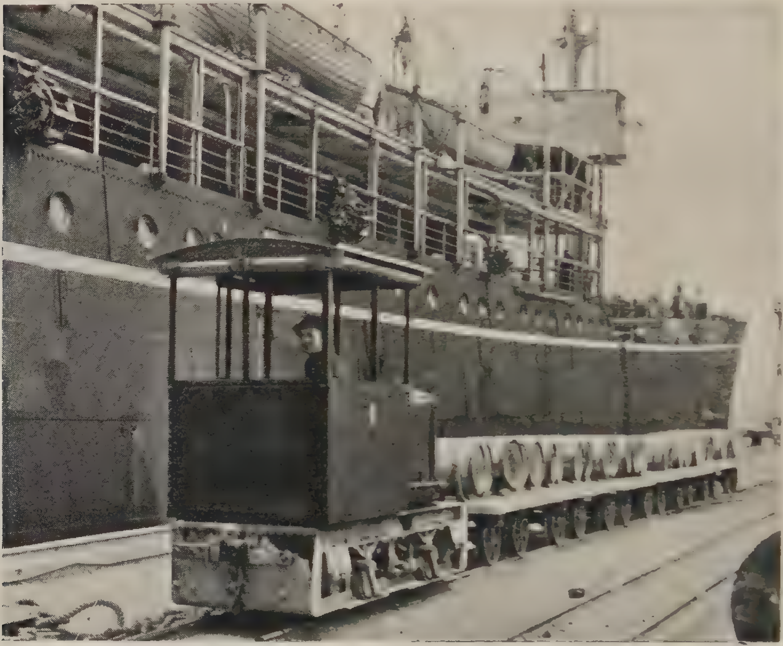


Fig. 13.—Loading Large Steamers at Bevans Jetty.

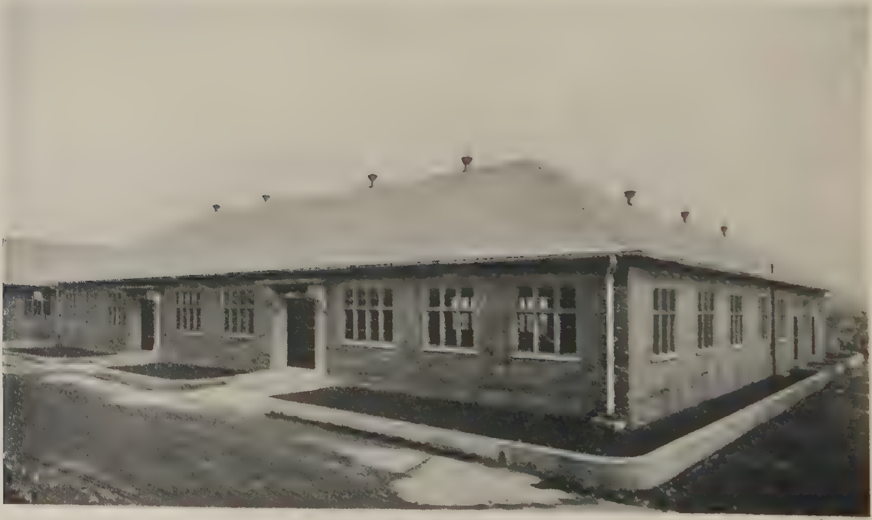


Fig. 14.—Bevans Works Canteen.

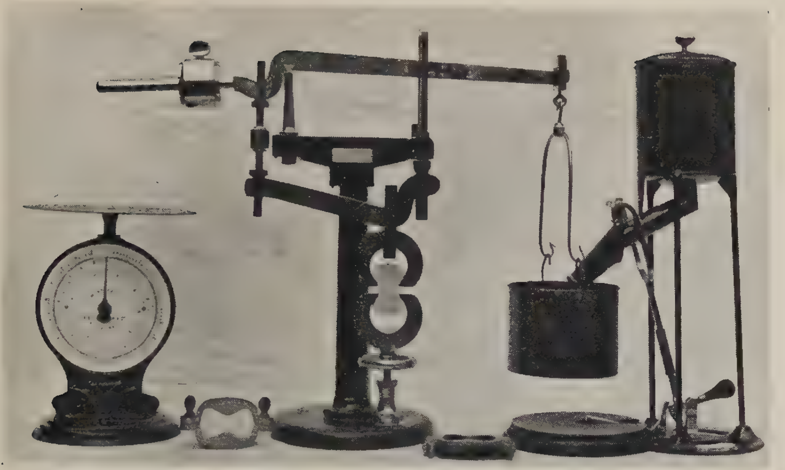


Fig. 15.—Tensile Testing Machine.

strength, when the cement is mixed with three parts of sand, should be not less than 325 lbs. per sq. in. Compression tests are made on cubes or cylinders cast in metal moulds. Soft wood, lead, or plaster of Paris may be used for bedding the test pieces and ensuring an even distribution of the pressure. Machines for compression tests are illustrated in *Figs.* 17 to 20.

" Ferrocrete " Rapid-hardening Portland Cement

The inconvenience caused by the delay of 28 days which ordinary Portland cement takes to attain approximately maximum strength led cement manufacturers to concentrate on the production of a Portland cement that would harden in a shorter period. In this they were successful,

TABLE I.

Comparison of Tensile Strength of Ordinary and Rapid-hardening Portland Cements in lbs. per sq. in. at Various Ages

	Age.					
	3 days.	7 days.	28 days.	3 months.	6 months.	1 year.
Ordinary Portland cement mortar (3 standard sand, 1 cement)	350	550	600	625	650	675
" Ferrocrete " rapid-hardening Portland cement mortar (3 standard sand, 1 cement)	650	750	790	800	805	820

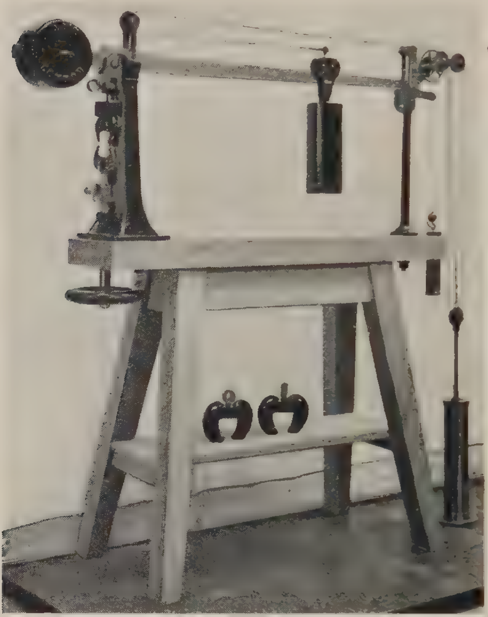


Fig. 16.—Tensile Testing Machine.

and in 1924 "Ferrocrete," the first rapid-hardening Portland cement, was put on the market by the Cement Marketing Company Limited. This Portland cement attains in two or three days the same strength as ordinary Portland cement in 28 days. Not only is great strength reached at an early age, but this increased strength is maintained, so that at any age concrete made with "Ferrocrete" is stronger than ordinary Portland cement. This is shown in the table (see page 17) giving the results of tests on similar test-pieces of ordinary Portland cement and "Ferrocrete" over a period of one year. Table 1 is a comparison of the tensile strength of ordinary Portland cement and "Ferrocrete" rapid-hardening Portland cement at various ages. Table 2 shows the compressive strength of "Ferrocrete" rapid-hardening Portland cement concrete from 24 hours to 28 days.

TABLE 2

COMPRESSION STRENGTH OF 6-IN. CUBES MADE WITH "FERROCRETE" CEMENT IN THE PROPORTION OF 4 PARTS STONE COURT BALLAST, 2 PARTS STONE COURT SAND, 1 PART CEMENT

Percentage of water used 6·3 per cent.

	Age of Cubes.					
	24 hours.	2 days.	3 days.	5 days.	7 days.	28 days.
	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
	2,010 2,250 2,120	3,150 3,260 2,970	4,050 3,710 3,980	4,940 4,780 4,720	4,960 4,940 5,340	6,250 6,200 6,130
Mean . . .	2,130	3,130	3,910	4,810	5,080	6,190

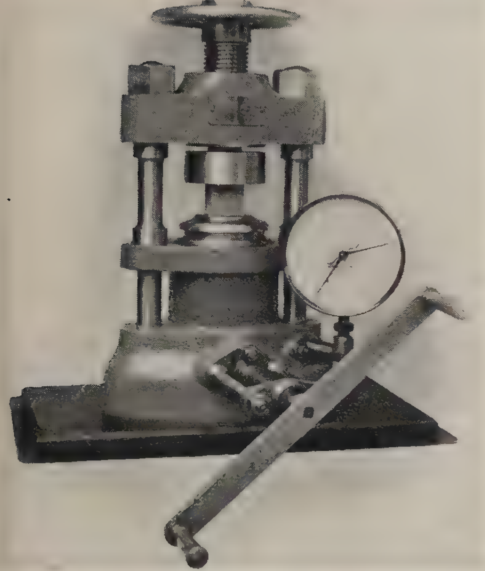


Fig. 17.—Compression Test Machine for 2¾-in. Cubes.

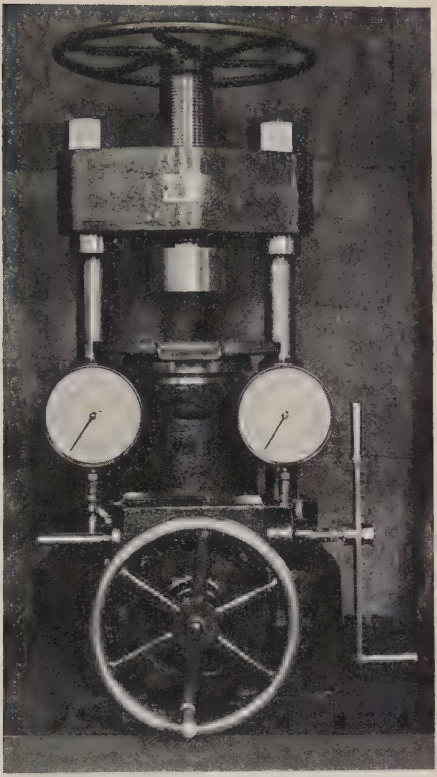


Fig. 18.—Compression Testing Machine for 6-in. Cubes.

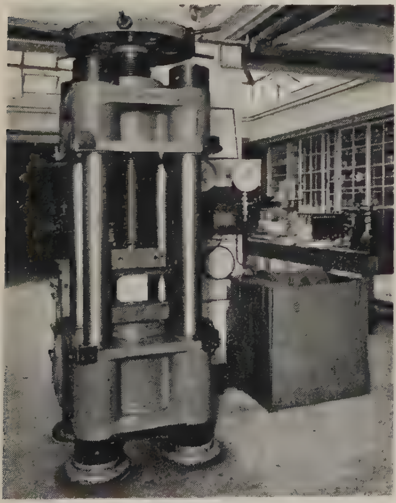


Fig. 19.—Compression Testing Machine.

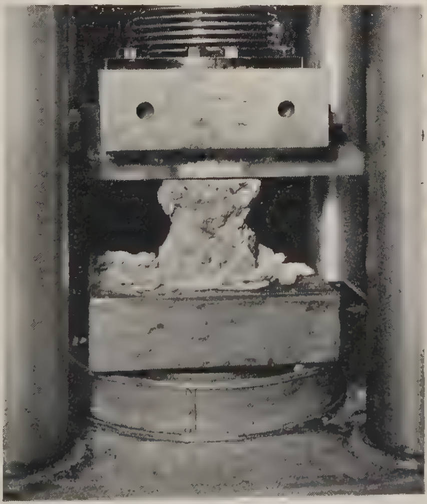


Fig. 20.—Pyramidal Fracture of Cube.

Saving in Forms.—The advantages of such a Portland cement are obvious, and for practically all purposes more than compensate for the small extra cost of rapid-hardening Portland cement. The saving in formwork is very great, as will be seen from the following periods after pouring at which forms may be stripped :

Column, beam or girder sides may be stripped in 24 hours.
Undersides of floor slabs ,, ,, ,, ,, 48 ,,
Undersides of beams and girders ,, ,, ,, ,, 3 to 6 days.

A saving of one-third of shuttering costs may easily be effected when " Ferrocrete " is used, and the earlier date at which a building may be used may represent very considerable sums.

With the use of " Ferrocrete " wet mix pre-cast concrete units may be removed from moulds 24 hours after casting, and used in building construction four days later. Piles may be stripped of their moulds in 24 hours, and driven in five or six days. Concrete roads may be opened to traffic six days after they are laid, or wood blocks or other surface may be laid 48 hours after the concrete foundation is placed.

In cases where speed of construction is not essential, and where extra expenditure on a Portland cement with special rapid-hardening properties would not seem to be warranted, economy may still be effected by taking advantage of the extra strength of " Ferrocrete." Existing regulations do not always permit full advantage to be taken of this extra strength by increasing stresses on concrete made with rapid-hardening Portland cement, but many authorities, including the Ministry of Transport, now permit stresses of 750 lbs. per sq. in. on concrete made with " Ferrocrete " as compared with 600 lbs. per sq. in. in the case of ordinary Portland cement concrete for the same mixture.

Resistance to Frost.—" Ferrocrete " is also less liable to damage by frost. It is obvious that the sooner the concrete hardens the less the danger of it being ruined by frost, for the period during which it is liable to damage is reduced. Conditions that would completely spoil ordinary cement concrete one day after placing would have no effect whatever on concrete made with rapid-hardening Portland cement. In a period of frost it is essential to protect ordinary cement concrete for at least two days after placing, but at twenty-four hours rapid-hardening Portland cement has passed the stage when frost can have any harmful effect. The use of rapid-hardening cement will thus reduce the cost of protecting newly-placed concrete, while, perhaps more important still, the period of risk during which concrete is liable to damage from excessive cold is also reduced by half.

Heat generated by cement whilst hardening is particularly noticeable in rapid-hardening cements. It is now generally accepted that the amount of heat generated by all cements during the hardening period is about the same, but that the dissipation of this heat is spread over the whole period of hardening. Thus the shorter the hardening period the greater the rise in temperature; this is particularly noticeable with aluminous cements, which reach very high temperatures when first mixed and placed. In this connection, during winter construction work in 1928 a floor slab, 2 ft. thick, made with "Ferrocrete" rapid-hardening Portland cement, was poured just before a spell of frost lasting for ten days. During the whole of this period the ground around the slab was frozen hard, but there was no sign of freezing on the slab, which was, in fact, covered with shallow pools of water.

Practical Tests on "Ferrocrete."—The following is taken from a report by Dr. Oscar Faber, O.B.E., D.Sc., M.Inst.C.E., on some tests undertaken under his direction at the City and Guilds Engineering College, London:

"A series of test beams of reinforced concrete 16 ft. long was designed, and reinforced identically so that the only difference between them was that half were made with ordinary Portland cement and half were made with 'Ferrocrete' rapid-hardening Portland cement. These were made by Messrs. Jackaman & Son, Ltd., under practical conditions. Cubes of the concrete used in these test beams were also made, and the beams and cubes sent to a laboratory for testing.

"The beams were tested at the City and Guilds (Engineering) College, South Kensington, where the experience of Professor S. M. Dixon and Professor J. Purser had been secured.

"*Fig.* 21 is a curve in which the crushing strength of the cubes is plotted against the age in days. Curve A, being the strength for the ordinary concrete cubes prepared by the contractor, gives a strength in 4 days of about 1,200 lbs. per sq. in., increasing in 28 days to about 1,600 lbs. and 2,566 lbs. in 3 months. These are the variations commonly found in curves of this kind, and the results are of course lower than the corresponding laboratory tests for the same materials. Curve B gives the results of concrete made with the rapid-hardening Portland cement, also by the contractor's workmen. At 4 days the results are approximately 4,100 lbs. per sq. in., increasing up to about 5,350 lbs. at 28 days and 5,900 lbs. or more at 3 months. *In other words, at 4 days 'Ferrocrete' concrete is over $3\frac{1}{2}$ times, at 28 days over $3\frac{1}{4}$ times and at 3 months approximately $2\frac{1}{4}$ times as strong as ordinary Portland cement.*

"On the same figure are given two other curves, C being the test cubes on ordinary cement from the same works, prepared by Messrs. Riley, Harbord and Law, made under laboratory conditions and kept at standard temperatures for the whole length of their maturing. Curve D shows the strength of similar cubes made by the same testers, but of the same rapid-hardening Portland cement used for the test beams; these tests (dotted on the figure) are in both cases higher than those made by the contractor, and this is to be expected. This difference is particularly marked between 14 and 28 days, and is largely due to the fact that the test beams and cubes made by the contractor were taken out into the cold December weather when they were 14 days old, whereas the cubes made by the testing firm were kept under standard temperature conditions to the end. Had the specimens been kept in a moist temperature for the whole period they would have shown a much bigger increase in strength, and the curves A and B on *Fig.* 21 would have approximated more closely to curves C and D respectively.

" *Fig.* 22 gives the corresponding results of the test beams. The curves in *Fig.* 22 would also have shown a greater rate of growth, as concrete grows very little in strength at low temperatures.

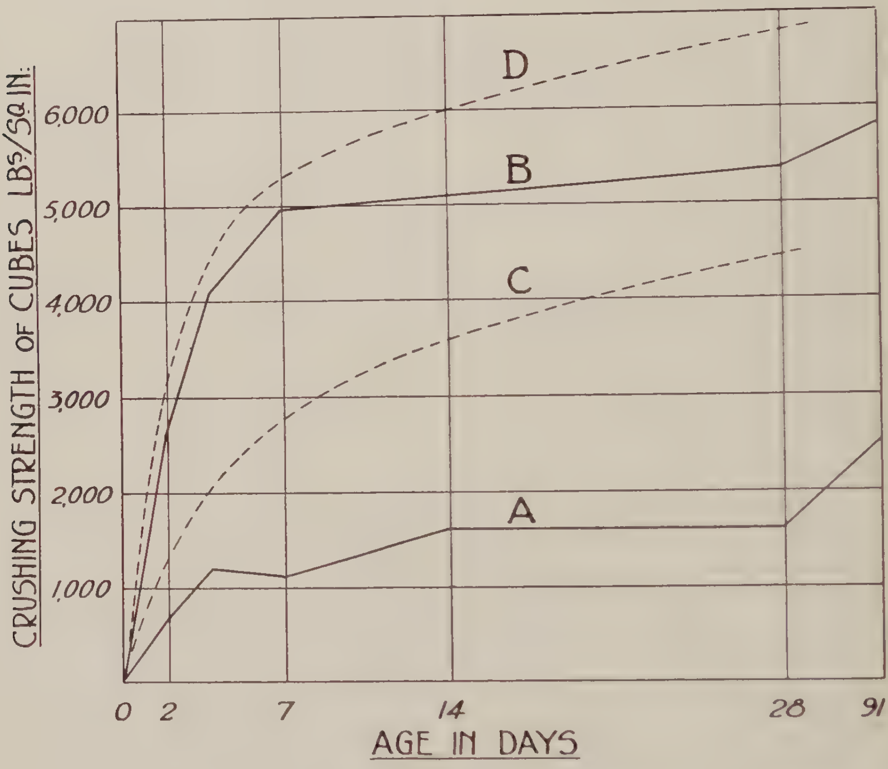


Fig. 21.

A = Average P.C. made by Contractor. B = " Ferrocrete " P.C. made by Contractor. C = Average P.C. made in Laboratory. D = " Ferrocrete " P.C. made in Laboratory.

" Curve A is the load causing fracture on the beams made with ordinary concrete and curve B the breaking load on the beams made with the rapid-hardening concrete. At 4 days the ordinary concrete beams carried about 6,500 lbs. ; at 28 days about 12,200 lbs. ; and at 3 months about 17,000 lbs. The corresponding figures for the rapid-hardening Portland cement are 19,000 lbs. at 4 days ; 27,750 at 28 days ; and 27,025 at 3 months. The beams made of the rapid-hardening cement are therefore approximately three times as strong as the other at 4 days, twice as strong at 28 days, and one-and-a-half times as strong at 3 months. The curves do not indicate any reduction in strength, even relatively, and indicate that this ratio of strength would be maintained at greater ages.

"*Fig.* 23 shows the relationship between the applied load and the deflection of the beam in inches. To avoid confusion only four curves are shown on this diagram : A_1 and A_9 being beams of ordinary concrete tested at 2 days and 28 days respectively ; B_1 and B_9 being beams made with rapid-hardening cement at 2 days and 28 days.

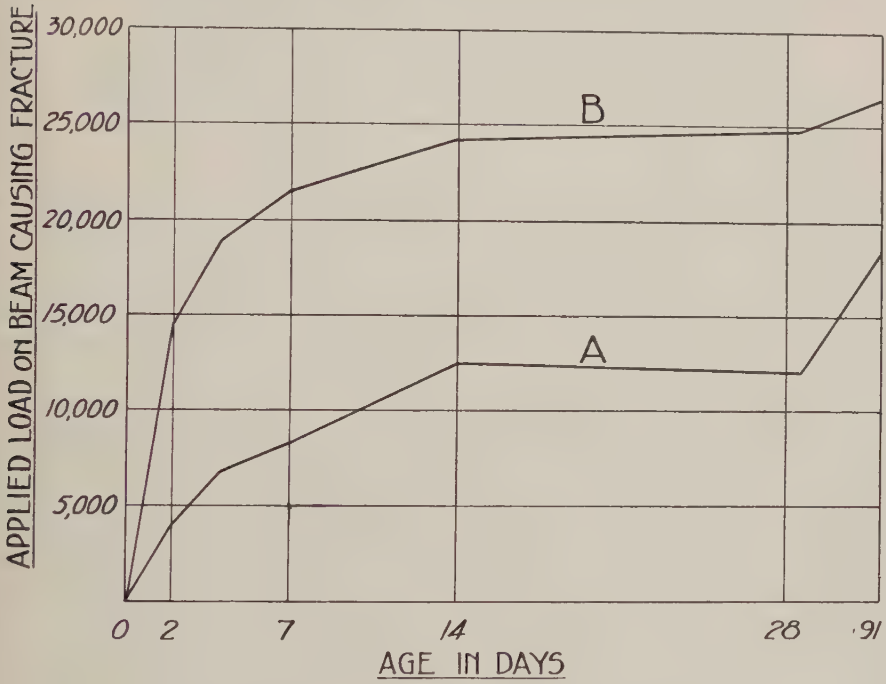


Fig. 22.

A = Average P.C. Concrete. B = "Ferrocrete" P.C. Concrete.

"In all cases a deflection of just over 1 in. is reached at fracture, independently, or almost so, of whether the beams carried a load of about 3,500 lbs. as in the case of A_1, or 25,600 as in the case of B_9. In other words, the rapid-hardening Portland cement not only carries a far greater stress than ordinary concrete, but at practically no increase of deflection ; its modulus of elasticity is increased roughly in proportion to its increased strength. A beam made with this rapid-hardening Portland cement will carry two or three times the load of a beam made with ordinary cement without an increase in deflection. The result is an especially interesting one and bears on the London County Council Regulations for reinforced concrete under the 1909 Act, in which the modulus of elasticity is made to depend on the crushing strength of the concrete, a theory which is strikingly borne out by these tests, whether that increase of strength is obtained by the increasing age of the specimen or by the use of superior cement."

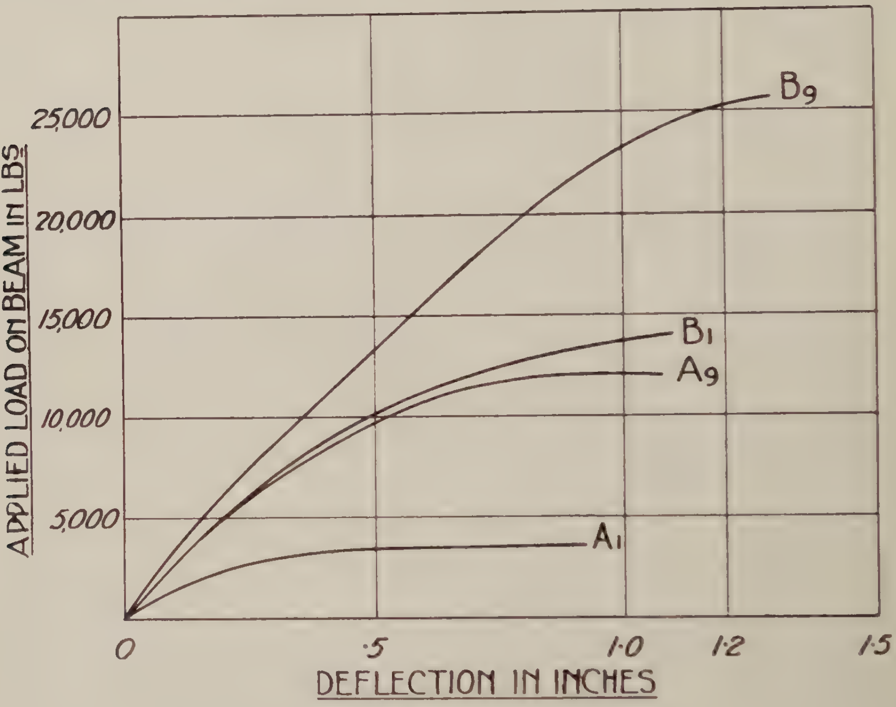


Fig. 23.

A_1 = Beams of ordinary Concrete 2 days old. A_9 = Beams of ordinary Concrete 28 days old. B_1 = Beams of "Ferrocrete" Concrete 2 days old. B_9 = Beams of "Ferrocrete" Concrete 28 days old.

Aluminous Cement

Although aluminous cement does not come in the same category as Portland cement, it is very useful owing to its extreme rapid-hardening properties. Originally made in France only, it is now produced in Great Britain and sold by the Cement Marketing Co. Ltd., under the trade name "Lightning."

Aluminous cement is manufactured by melting a mixture of bauxite (a mineral composed largely of alumina) and lime. The fused material is ground to the usual fineness. The high cost of the cement is due to the

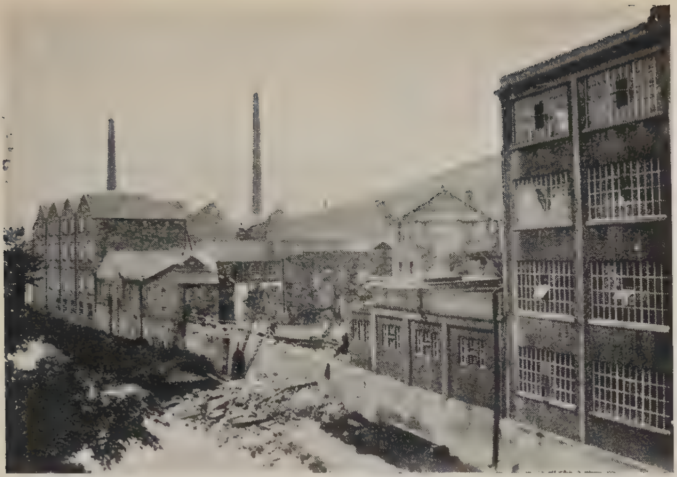


Fig. 24.—Reinforced Concrete Buildings intact after adjoining Buildings had been completely destroyed by Fire.

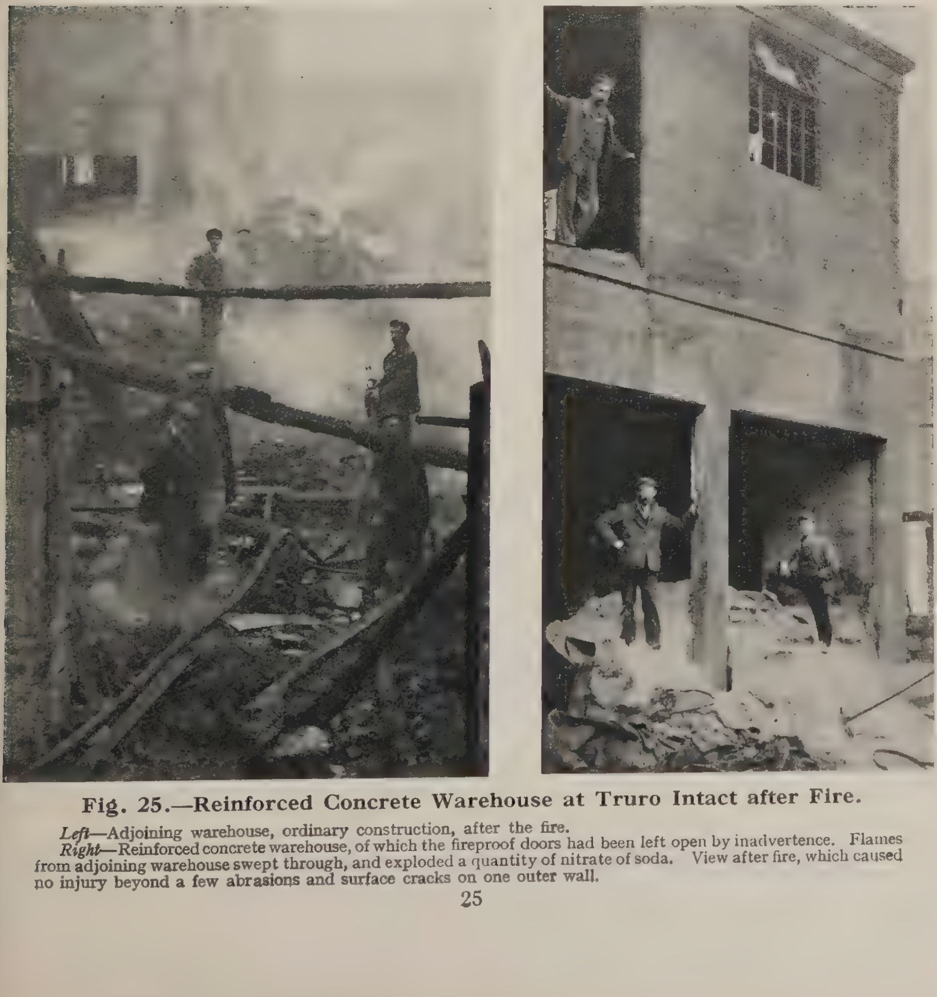


Fig. 25.—Reinforced Concrete Warehouse at Truro Intact after Fire.

Left—Adjoining warehouse, ordinary construction, after the fire.
Right—Reinforced concrete warehouse, of which the fireproof doors had been left open by inadvertence. Flames from adjoining warehouse swept through, and exploded a quantity of nitrate of soda. View after fire, which caused no injury beyond a few abrasions and surface cracks on one outer wall.

high cost of bauxite, and of fusing and grinding. Aluminous cement complies with the tests of the British Standard Specification for Portland cement, except that its chemical composition is different. A good aluminous cement may be expected to possess a tensile strength (3 parts sand to 1 part cement) of 450 lbs. per sq. in. at 24 hours, and a compressive strength of 5,000 lbs. per sq. in. at the same age. Tests have proved that an aluminous cement concrete only a day old has the strength of concrete one month old made with ordinary cement. Piles made of aluminous cement have been successfully driven when only 24 hours old. When aluminous cement is used in the manufacture of pre-cast concrete goods it is possible to use hand-tamping methods for such articles as fence posts, sills, etc., and use the same mould three times in one day.

A valuable quality of aluminous cement is its comparative immunity from attack by frost during setting. When aluminous cement sets it generates heat rapidly, owing to the intensity of the chemical action that causes the rapid hardening, and this heat often prevents the concrete becoming frozen until it is hard enough to resist freezing action without damage.

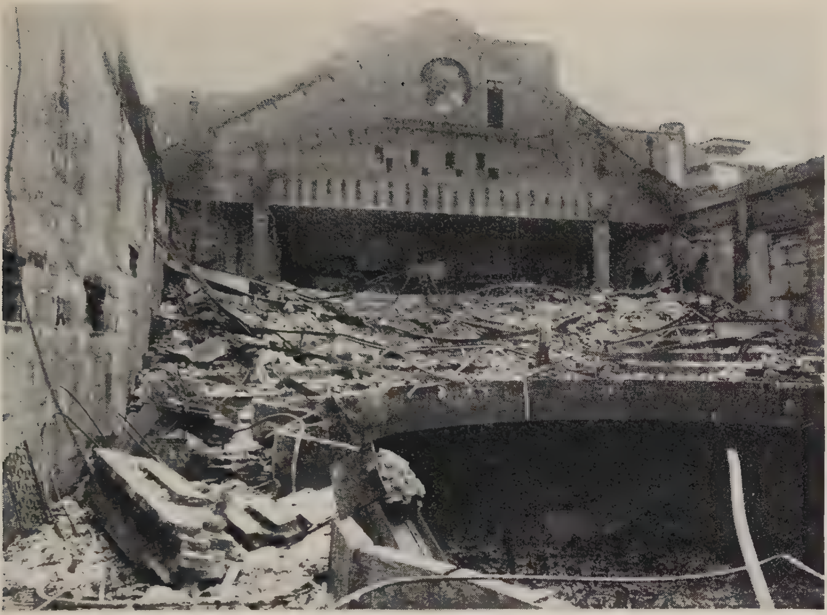
Aluminous cement is used in the same way as ordinary cement, but as contamination with Portland cement or lime is liable to cause flash setting, it is necessary to employ mixers, mixing boards, barrows, shovels, and other accessories that have been carefully cleaned of any trace of ordinary cement or concrete ; also, as soon as the cement is set—usually within four to six hours —the concrete must be kept wet for about 24 hours in order that the water that may be evaporated by the heating of the concrete may be replaced.

White Cement

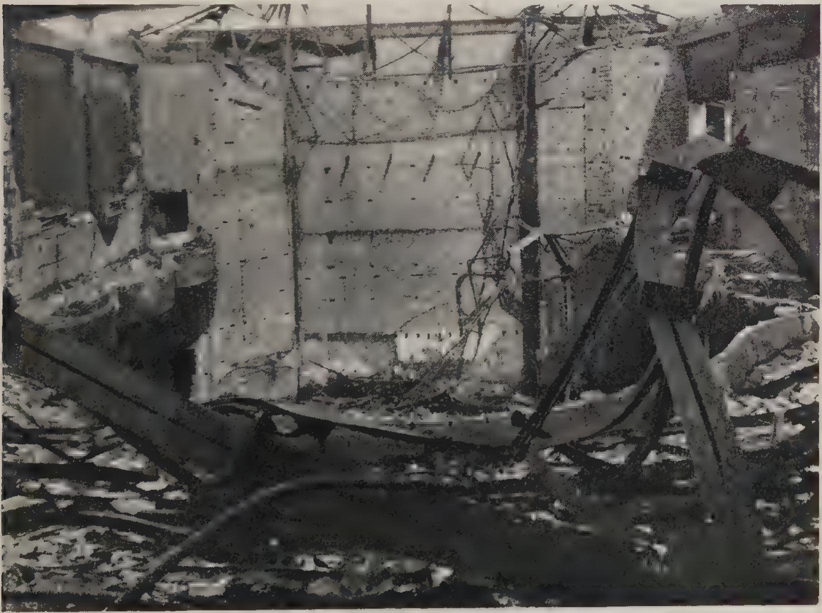
For many purposes, such as matching certain light shades of natural stone, and for white stucco, a white cement is necessary. For such uses pure white Portland cement known as "Snowcrete," the first white Portland cement to be made in this country, is supplied by the Cement Marketing Company Ltd. This is a true Portland cement ; it has the same properties as ordinary grey Portland cement, and is used in exactly the same way. Owing to the difficulty of obtaining the necessary raw materials and increased manufacturing costs the price of white Portland cement is higher than that of grey Portland cement, and for this reason it is generally used for facing only ; the cost of "Snowcrete," however, is considerably less than that of the imported white cements which until this year (1929) were the only white Portland cements available in Great Britain.

Coloured Cement

By the addition of mineral oxides, white Portland cement can be coloured to any shade. The colour may be added to the cement when the concrete is mixed, but the risk of lack of uniformity in colour that may result from this method may be avoided by purchasing cement ready coloured.



Reinforced concrete balcony intact and covered with wreckage.



The only parts remaining intact and free from injury after fire were the reinforced concrete balcony and the café and street frontage protected by the reinforced concrete balcony.

Figs. 26 and 27.—Reinforced Concrete Intact after Cinema Fire.

The Cement Marketing Company Ltd. supplies cement coloured to any shade to meet customers' requirements, in which the colours are mixed under factory conditions and expert supervision, and in which pure white "Snowcrete" cement is used as the base. A special brand of coloured cement, known as "Colorcrete," gives a pleasant buff shade, and is particularly suitable for concrete roads owing to the absence of glare on the surface.

AGGREGATES

Generally speaking, any inert material of a suitable size, and free from undesirable constituents, may be used as aggregate in concrete. There are, however, certain requirements, particularly cost and strength, which limit the choice of material. Because sand, gravel, and ballast, either from pits or river beds, are the strongest and cheapest inert materials present in abundance in or near almost every district, these are the materials generally used as concrete aggregates.

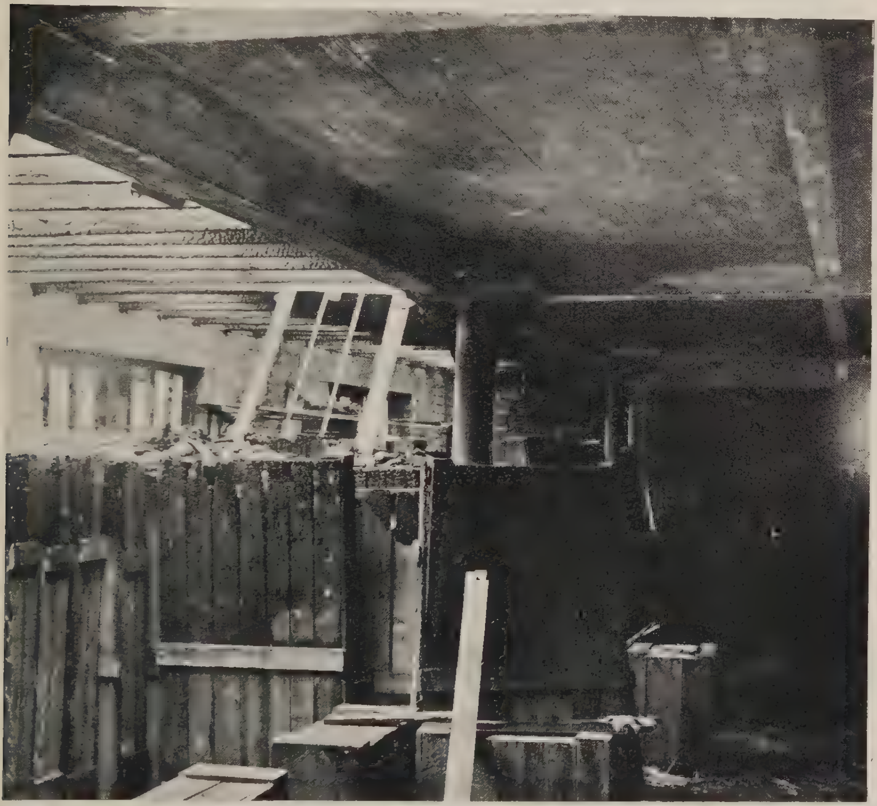
Where they may be obtained cheaply in sufficient quantities, stone chippings and slag make strong concrete, but sand and gravel cannot be improved upon for ordinary concrete work. Other materials often used as aggregate are clinker, breeze, ashes, and broken brick. These are likely to contain impurities.

For the purpose of obtaining maximum density in concrete (see Part II, "Grading"), aggregate is divided into two classes, known as "fine" and "coarse." Fine aggregate, usually sand or crushed stone, is generally material which will all pass a $\frac{1}{4}$-in. sieve; coarse aggregate is material up to any size that can be used in practice but which will all be retained on a sieve with $\frac{1}{4}$-in. openings.

Whatever the material used for fine or coarse aggregate it must be free from impurities that would affect the setting of the cement or ultimate strength of the concrete, and without an excessive proportion of dust. The value of cement lies in its property of combining masses of stone together by reason of its adherence to individual grains of sand or pieces of stone, but if the sand or stone is already coated with loam or clay or other foreign matter it is obvious that the cement can only come into contact with and adhere to a film of foreign matter, thus making the strength of the concrete depend upon the adhesion between the sand or stone and its covering layer. When concrete containing dirty aggregates is broken up it is frequently found that the pebbles are easily detached from the mass, and an examination of the surrounding concrete reveals a layer of foreign matter.

Another effect of dirty aggregates is that the mud or organic matter they contain mixes with the cement and prevents the latter from setting and hardening. One of the most frequent causes of complaint concerning concrete is failure to harden, and in many cases the cause is the contamination of the cement with mud, or organic matter from the aggregate. Such complaints are more noticeable in cold and damp weather, because the mud remains in a more or less colloidal state; but if the aggregate can be dried the mud becomes gritty, and in this condition it interferes less with the setting of the cement.

Test for Cleanliness.—A dirty aggregate can sometimes be detected by rubbing some of it between the hands and observing the staining effect, but a better test is to stir a handful of the sand or stone with water in a glass jar, when the loam or clay will, on settling, form a layer by itself. If the jar be marked with divisions it is possible to ascertain the proportion of loam in the aggregate by comparing the thickness of the layer of loam with that of the sand or stone. Some specifications for reinforced concrete limit the amount of clay or loam in sand to 3 per cent., but it is perhaps hardly



Fire broke out in the upper part of this building, which was gutted. One of the upper floors was partly in reinforced concrete and partly in wood. The illustration shows how the concrete floor to the right protected the structure beneath it, while the wood floor and the parts beneath it were consumed.

Fig. 28.—Reinforced Concrete Floor Prevents Spread of Fire at Newcastle-on-Tyne.

desirable to lay down a rule as to the proportion of loam that is permissible in concrete aggregates, because much depends on the nature of the loam and whether the concrete will be in a warm and dry atmosphere or wet and cold. Some aggregates containing as much as 10 per cent. of loam are used with success, while, on the other hand, the presence of less than 5 per cent. of loam seriously interferes with the hardening in some cases. To be on the safe side, it is advisable to wash all aggregates liable to be dirty, and especially pit sands and ballasts. The latter are subject to great variations as they are dug, and frequent examinations and tests as above are desirable when such aggregates are used.

Tests for Impurities.—Sand or gravel containing organic matter (vegetable débris or animal refuse) is particularly objectionable, but there is a simple test for organic matter which can be applied by clerks of works or foremen without difficulty. The test is conducted by shaking some of the sand in a glass bottle with a 3 per cent. solution of caustic soda and allowing the mixture to stand for 24 hours. The amount of caustic soda solution used should be such that when in the bottle the bulk of solution should be about equal to the bulk of sand. If after standing for 24 hours the colour of the solution is no more than a pale yellow the sand may be assumed to be free from objectionable organic matter, but if the colour is a marked yellow or brown the presence of organic matter is indicated, and such sand would not produce a good quality concrete.

Types of Aggregate

Stone.—Crushed stone and stone chippings make a good concrete, but if the material is flakey when obtained it is advisable to pass it through a crusher in order to obtain a less flakey aggregate and therefore a stronger concrete than would otherwise result.

Crushed stone often contains a considerable proportion of very fine material, and if this is the case it is very necessary to ensure that this is in fact stone-dust. In the process of crushing, clay and other foreign materials will remain in the broken stone, and if these are present in any considerable proportion they will have a deleterious effect on the strength of the concrete. It is generally advisable to make some tests with the material in order to ascertain its suitability. It is advisable to remove any excess of dust, as its presence will result in weak concrete.

Clinker and Breeze. In many districts it is possible to obtain an abundant and cheap supply of clinker, and this is extensively used for the manufacture of blocks and slabs. Clinker concrete is not weatherproof, neither is it as strong as gravel concrete, but it is quite suitable for unreinforced walls where no great strength is required, such as cottage, garage and partition walls, etc. If used for external walls it must be waterproofed with a cement rendering. Clinker as received from the destructor or other source usually requires crushing, and particular care should be taken to ensure that

Fire broke out in upper part of building, used for storage of paint, etc. These two views show upper part destroyed, the lower part having been preserved by reinforced concrete floor on which roof and other débris fell.

Figs. 29 and 30.—Reinforced Concrete Intact after Severe Fire.

it is free from sulphur and unburnt coal, the presence of which will cause "blowing" and result in a material that is not fire-resisting. On no account should breeze be used for reinforced concrete, as the possible presence of sulphur and the porous nature of the material will result in the destruction of the steel.

Test for Sulphur in Clinker.—The method of testing clinker or breeze for the presence of sulphur is as follows:

A sample of the clinker is finely ground and placed in a test tube, and to it is added hydrochloric acid diluted to three times its own volume. The test tube is warmed over a Bunsen flame, and a lead acetate paper (obtainable from most chemists) placed over the mouth of the tube. If the fumes discolour the paper, turning it a metallic brown, sulphur is present. The presence of sulphur can also be detected by the smell of sulphuretted hydrogen when the tube is warmed. If sulphur is indicated by this test, an analysis should be made to ascertain the proportion. It is generally considered that a sulphur content of 0·4 per cent. is the limit that can be permitted with safety.

Brick.—With broken brick there is the possible danger of lime being included from adhering mortar or sulphate of lime from "Sirapite" or other plaster, so that broken brick is not always safe to use as an aggregate unless it has been cleaned. Certain classes of brick made from clay containing pyrites are liable to contain sulphur in an active form, and when this is the case concrete containing such broken brick is liable to swell and crack after setting, especially if in a damp situation. Broken brick is, of course, a porous aggregate, and all porous aggregates (and these include some varieties of stone) should be well soaked with water before use, otherwise they will absorb from the concrete the water required for the setting action of the cement, thus causing imperfect hardening and cracking of the concrete. Some porous aggregates are slow in absorbing water, and it is therefore safer to soak them with water the day before use and again immediately before use.

Ashes.—A light-weight concrete may be obtained by the use of ashes and cinders, usually obtained from gas-works or industrial plants. It is essential that they should have no trace of unburnt coal or sulphur, which, although in small quantities do not appear to affect the fire-resisting properties of concrete, are liable to cause the concrete to expand after it has set.

Coke Breeze.—Coke breeze is also a cheap aggregate for blocks and slabs where no great strength or watertightness is required, or where they are to be weather-proofed by rendering or roughcast. It is necessary, as with ashes, to make sure that the breeze contains no appreciable proportion of sulphur or partially-burnt coal. As in the case of clinker, coke breeze must not be used for reinforced concrete.

Slag.—Blast-furnace slag makes a heavy concrete, and as it has a high fusing point it is often used in places where it is likely to be subjected to

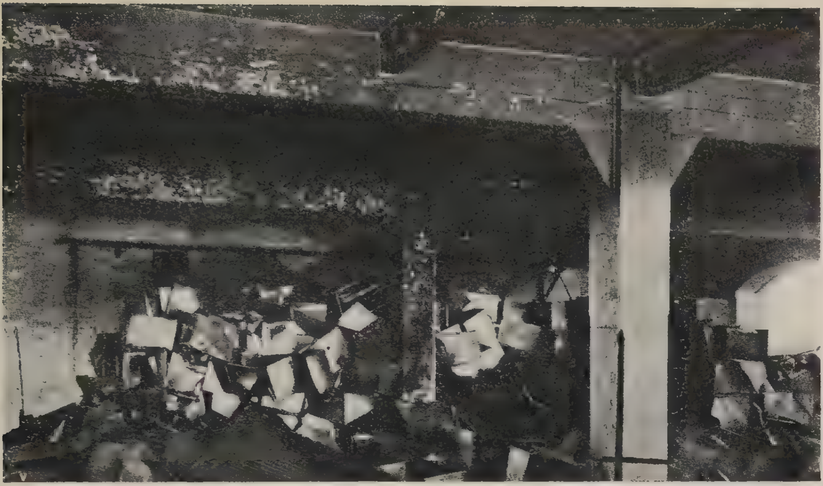


Fig. 31.—Reinforced Concrete Beams and Columns Intact after Silvertown Explosion and Fire, 1917.

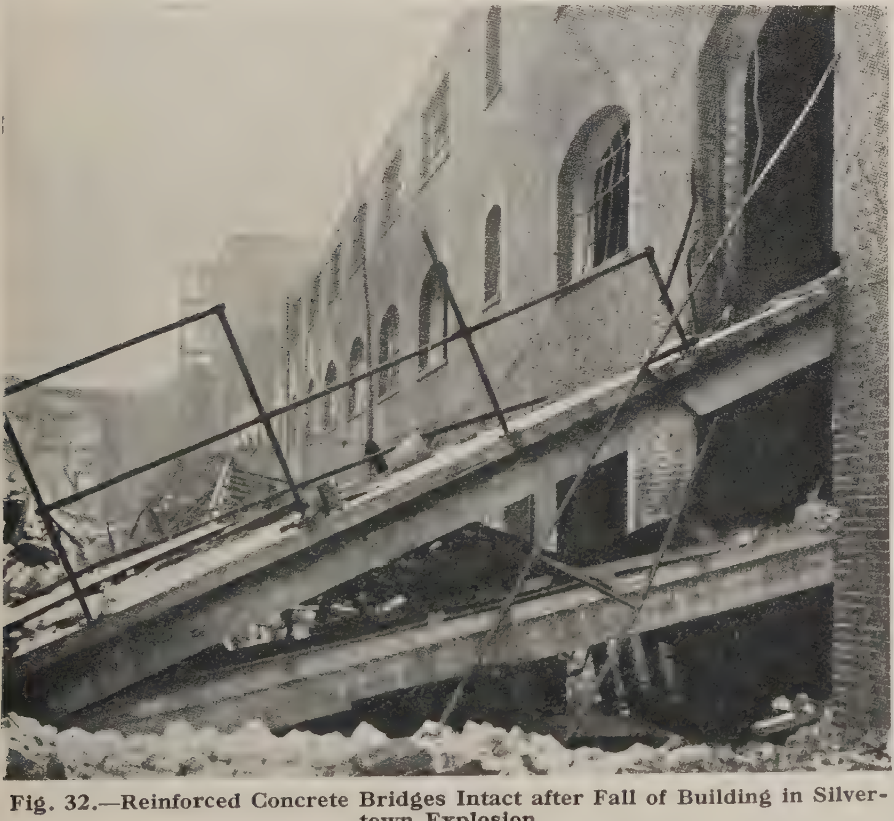
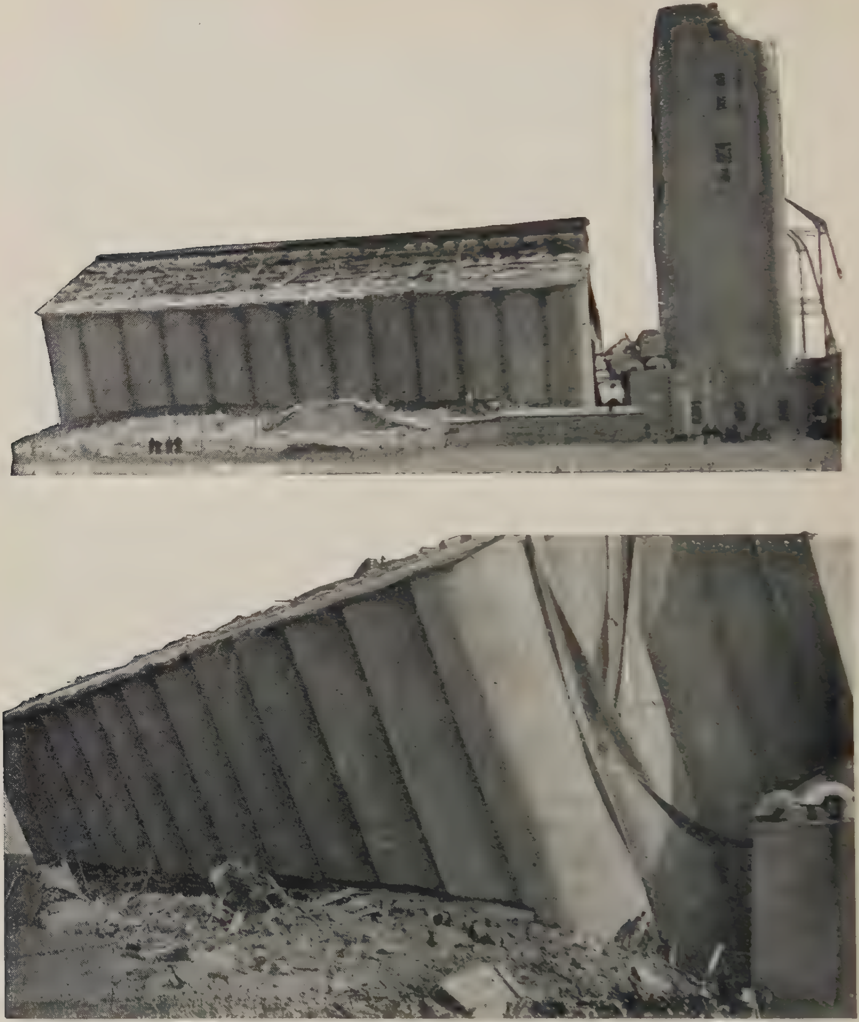


Fig. 32.—Reinforced Concrete Bridges Intact after Fall of Building in Silvertown Explosion.



Figs. 33 and 34.—Two Views showing the monolithic nature of reinforced concrete. Due to subsidence this structure tilted to 28 degrees from the vertical without injury, and was restored to its original position at nominal cost.

high temperatures. It must not contain more than about 0·5 per cent. of sulphur.

Sawdust.—Concrete made with sawdust aggregate weighs about half as much as ballast concrete, and according to the grade of sawdust used has been shown by tests to have reached a compressive strength at 28 days of up to 2,000 lbs. per sq. in. The sawdust is treated with calcium chloride. Concretes made with sawdust aggregates can be cut with a saw, and will also take nails and screws. The mixing and moulding of concrete with sawdust aggregates are carried out in the same way as with other types of aggregates. A pair of concrete gates made with sawdust as aggregate, and which are in good condition after several years' use, is shown in *Fig.* 35.

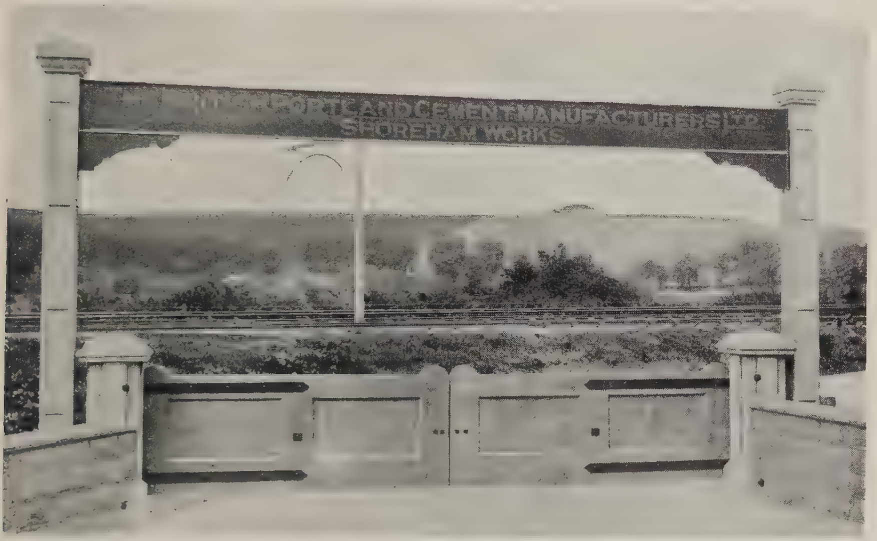


Fig. 35.—" Sawdust-Concrete " Gates.

Special aggregates for use with "Snowcrete" white Portland cement are now supplied at our depots.

FIRE-RESISTANCE

For all ordinary concrete work gravel, ballast, and the aggregates usually employed are quite satisfactory so far as fire-resistance is concerned, but if the concrete is likely to be subjected to great heat siliceous aggregates should not be used owing to their liability to expansion and consequent spalling when exposed to fire.

LIGHTWEIGHT CONCRETE

There are now on the market several types of lightweight concrete. In some of them the lightness is obtained by mixing specially-prepared materials with the cement; in others by using a very light material, such as pumice and sawdust, as aggregate; while in others a low density is obtained by the use of an aggregate such as clinker without filling the voids with sand.

" Expanded " Concrete.—" Expanded," " aerated," or " cell " concrete, as the material produced by mixing materials with the cement which causes the mass to bubble is variously called, has been produced with a weight as low as 16 lbs. per cubic foot, and owing to the large proportion of air-pockets it contains it is particularly useful for insulating purposes, the air-pockets preventing transmission of heat through the concrete. (*Fig.* 36.) The material is also useful for all purposes where strength is not the primary consideration ; it is fire and weather-resisting, and, in spite of the innumerable holes on the surface, moisture does not percolate past the first two or three series of voids.

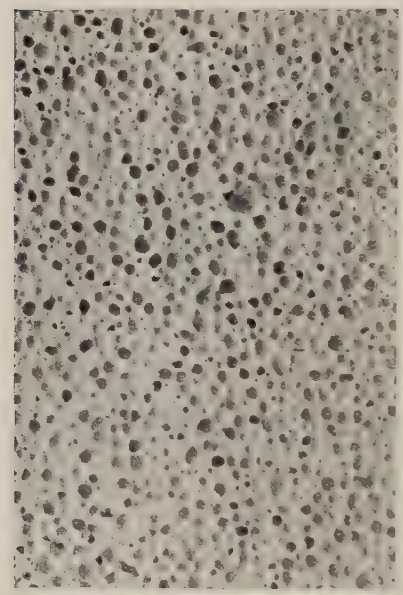


Fig. 36.—" Aerated " Concrete.

Clinker Concrete without Sand.—Lightweight concrete may be made by using a light aggregate, such as clinker, and omitting the fine aggregate. The material has air voids in place of fine aggregate, the clinker touching on points only ; thus it has no great strength, but the large proportion of air-pockets acts as an excellent non-conductor of heat and cold. This type of lightweight concrete has been fairly extensively used for houses, first in Holland and more recently in this country. The clinker used has a maximum size of ¾ in., from which all material finer than ¼ in. is removed. This is mixed with Portland cement in the proportion of about 8 to 1, and produces a concrete with about 50 per cent. of voids. Experiments have shown that in such a concrete damp will not penetrate beyond the area of the first void, or a depth of about 1 in.

Ice Concrete.—Another lightweight concrete is known as "ice concrete." This is a Scandinavian invention, protected by patents, by which small particles of ice are used to form a concrete with a large proportion of voids, similar in appearance to that produced by chemical means and marketed in this country as "Aerated concrete." The principle is as follows : Sand and cement are mixed dry in the usual way, but instead of adding water a proportion of finely-crushed ice is added to the mix. This mixture of sand, cement, and small pieces of ice is then placed in a mould and taken to a warm room. Here the ice melts, and percolates through the mass as water, leaving cavities in place of ice. During the process of mixing each piece of ice is coated with cement, so that when it has melted the mass is in fact a honeycomb of thin walls of cement that previously coated the pieces of ice. The ice may be natural or made by artificial means. The material is stated to have a fair degree of strength, and to be watertight owing to the fact that each cell is completely surrounded by a thin wall of cement.

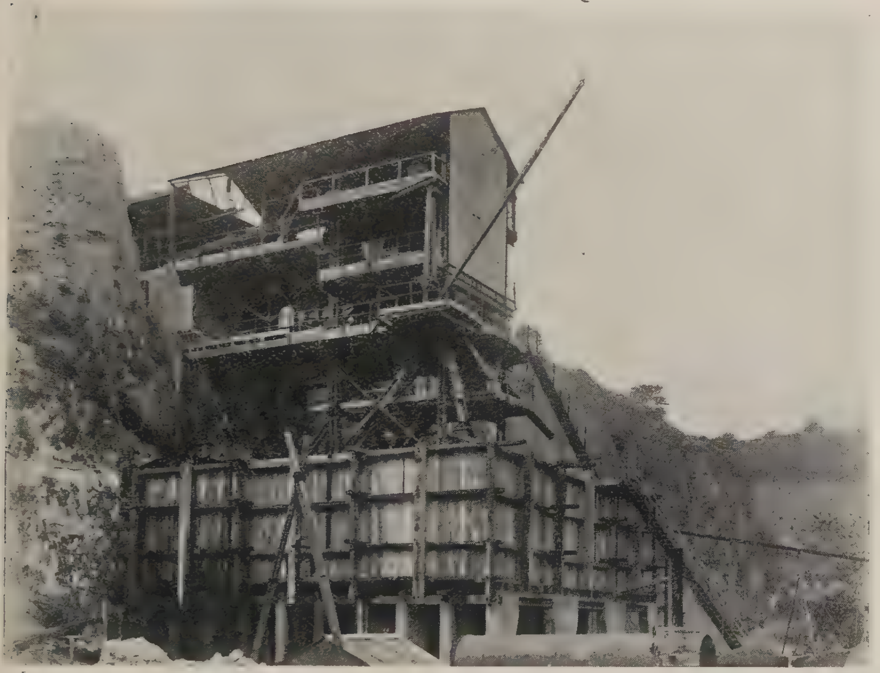


Fig. 37.—Aggregate Plant of Stone Court Ballast Company, Ltd. (Output over 6,000 tons a week.)

REINFORCEMENT

Steel for reinforced concrete work may be divided broadly into four classes, viz.:

(1) Mild steel round bars.
(2) Bars with indented or corrugated sides.
(3) Shop-made meshes of mild steel, and
(4) Shop-made meshes of high-tensile steel.

Each class has advantages under certain conditions but the first-named is most commonly met with in practice. Methods of bending, placing and wiring steel rods are discussed in Part II. Various patent meshes are illustrated and described in Part II.

Mild steel bars should comply with the requirements of the British Standard Specification No. 15 and be free from loose rust, scale, grease or paint.

CEMENT MORTAR

One of the disadvantages of lime mortar is that it requires frequent pointing. Mortar made by mixing cement, sand and water is extensively used for pointing brickwork laid in ordinary lime mortar, for laying brickwork in corbels, copings, stacks, etc., and where high strength is required as in arches and other structures laid in engineering bricks.

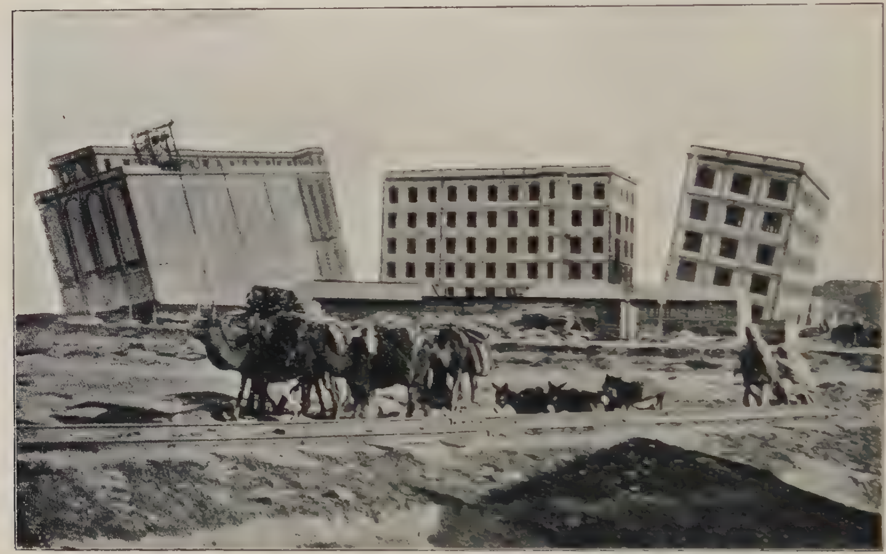


Fig. 38.—Reinforced Concrete Buildings Intact after Subsidence.

Built on the site of a dried-up lake, these large reinforced concrete buildings settled about 25 deg. out of vertical owing to an escape of quicksand under foundations. The buildings were safely levelled without injury. No cracks were caused, and even window glass was unbroken.

The proportions of sand and cement required vary according to the purpose for which the mortar is to be used from 2 to 1 to 4 to 1. The sand should not be very fine such as is suitable for plastering work. In making cement mortar it is necessary to mix it immediately it is required for use. Mortar which has commenced to set should always be rejected. Hand mixing on a mixing board has been general, but there are now on the market small types of hand-operated mixers which are claimed to reduce the labour costs of mixing and give a more homogeneous product.

In masonry cement mortar is used as a jointing material ; in some cases all the joints are made with cement mortar, in others the bedding joint is made with lime mortar and the vertical joints with cement mortar. The latter is also used for pointing masonry.

In the construction of brick sewers cement mortar is employed to make the joints. As in other brickwork the mortar must not be made excessively wet and the bricks depended on to absorb the excess water; in fact the bricks should have been well watered before they are laid. The practice of "larrying" or placing a pile of very wet mortar on top of the centre for the arch and then pushing the bricks into position by hand should never be countenanced.

Another of the uses of Portland cement mortar is in jointing earthenware or stoneware drain pipes, the usual mixture being 1 part of cement to 1 of fine sand. Recently rapid-hardening cements have been used for this purpose.

For structures where an attractive appearance is desired increasing use is being made of white and coloured cement mortar for pointing between brick or stone work. "Snowcrete" cement and white sand will give a perfect white joint, while attractive shades may be obtained by the use of "Snowcrete" and coloured sands. Any colour mortar may be made by using coloured cement and coloured sand by following the principles of making coloured concrete explained in Part III.

MEMORANDA RELATING TO CONCRETE MATERIALS

Cement.—1 ton of Portland cement = 10 sacks of 2 cwts. (224 lbs.) net each; or 11 sacks of 204 lbs. net each; or 12 sacks of 187 lbs. net each. "Ferrocrete" rapid-hardening Portland cement is supplied in 1-cwt. bags.

1 cu. ft. of Portland cement weighs from 75 to 90 lbs. when loosely filled in without any shaking, and about 110 lbs. when tightly packed. "Ferrocrete" has a greater volume for a given weight than ordinary Portland cement.

The Royal Institute of British Architects advises the adoption of 90 lbs. as the basis of comparison in converting cement from cu. ft. to lbs. for proportioning concrete. This has also been adopted as the standard by the London County Council in their Regulations for Reinforced Concrete Construction in London.

1 cu. ft. = 0·037 cu. yd. = 1,728 cu. in.

1 cu. yd. = 27 cu. ft. = 46,656 cu. in. = 1 load.

1 ton = 20 cwts. = 2,240 lbs. = 35,840 ozs.

Water.—1 cu. ft. of fresh water weighs 62·4 lbs. = 6·24 gallons = 0·037 cu. yd.

1 gallon of water = 10 lbs. = 0·16 cu. ft. = 277·46 cu. in.

1 cu. ft. of salt water weighs 64 lbs. = 6·24 gallons.

Concrete.—Average weight of 1 : 2 : 4 concrete: Coke-breeze as coarse material, 100 lbs. per cu. ft.; clinker, 110 lbs. per cu. ft.; brick, 125 lbs.

per cu. ft.; limestone, 135 lbs. per cu. ft.; shingle as coarse material, 145 lbs. per cu. ft.

Average weight of 1 : 2 : 4 reinforced concrete: 150 lbs. per cu. ft.

Sand and Aggregate.—1 ton = 21 cu. ft. river sand = 22 cu. ft. pit sand = 22 cu. ft. ballast = 23 cu. ft. coarse gravel = 24 cu. ft. clean shingle.

Reinforcement.—Safe adhesion strength of concrete to steel = 100 lbs. per sq. in. of area of metal.

Ultimate strength of mild steel in tension = 60,000 lbs. per sq. in.

Safe strength of mild steel in tension = 16,000 lbs. per sq. in.

Proportions of Cement for Concrete.—0·87 cu. ft. of neat cement mortar will result from mixing 0·36 cu. ft. of water with 1 cu. ft. of loose cement.

1 cu. ft. of loose Portland cement will make about:

4·1	cu. ft. of concrete mixed	1 : 2 : 4
5	,, ,, ,,	1 : 2½ : 5
5·8	,, ,, ,,	1 : 3 : 6
7·5	,, ,, ,,	1 : 4 : 8

Areas covered by 1 cu. ft. of Cement and Concrete.—1 cu. ft. of loose Portland cement neat as cement mortar will cover about 10·4 sq. ft. 1 in. thick.

1 cu. ft. of loose Portland cement to 1 sand will cover about 17 sq. ft. 1 in. thick.

1 cu. ft. of loose Portland cement to 2 sand will cover about 25 sq. ft. 1 in. thick.

1 cu. ft. of loose Portland cement to 3 sand will cover about 24 sq. ft. 1 in. thick.

1 cu. ft. of loose Portland cement to 2 sand will lay about 146 bricks with ⅜ in. joint or 247 bricks with ¼ in. joint.

1 cu. ft. of loose Portland cement to 3 sand will lay about 212 bricks with ⅜ in. joint or 317 bricks with ¼ in. joint.

1 yd. super of pointing brickwork in neat cement requires about 8 lbs. of cement.

100 lbs. of Portland cement and 1 cu. ft. of sand will plaster:

2¼ sq. yds.	1 in. thick.
3 ,,	¾ ,,
4¼ ,,	½ ,,

100 lbs. of Portland cement and 2 cu. ft. of sand will plaster:

3 sq. yds.	1 in. thick.
4¼ ,,	¾ ,,
6½ ,,	½ ,,

PROPORTION OF SOLIDS AND VOIDS IN VARIOUS COARSE MATERIALS.

Aggregates.	Solids.	Voids.
Sand, moist, fine, passing 18-mesh sieve (i.e., 324 meshes to the sq. in.)	0·57	0·43
Sand, moist, coarse, not passing 18-mesh sieve	0·65	0·35
Sand, moist, coarse and fine mixed, ordinary	0·62	0·38
Sand, dry, coarse and fine mixed	0·70	0·30
Stone screenings and stone dust	0·58	0·42
Ballast, ¾-in. and under, 6 per cent. coarse sand	0·67	0·33
Broken stone, 1 in. and under	0·54	0·46
Broken stone, 2½ in. and under, dust only screened out	0·59	0·41
Broken stone, 2 in. and under, most small stones screened out	0·55	0·45

MORTARS PRODUCED WITH ORDINARY (FINE AND COARSE MIXED) SAND.

Parts of sand mixed with 1 part of cement	1·0	1·5	2·0	2·5	3·0	3·5	4·0	5·0
Volume of slush mortar	1·4	1·78	2·17	2·55	2·98	3·39	3·82	4·65
Volume of dry facing mortar (rammed)	1·22	1·57	1·93	2·28	2·64	2·99	3·35	4·08

MATERIALS FOR 1 CU. YD. OF CONCRETE.

Based on loose cement weighing 90 lbs. per cu. ft. and a cu. ft. of loose, moist, coarse sand weighing 89 lbs. when dry.

Proportions.	Coarse Material.	Lbs. Portland Cement in 1 cu. yd.	Sand cu. yds. in 1 cu. yd.	Coarse Material cu. yds. in 1 cu. yd.
1 : 1 : 2	Shingle (40 per cent. voids)	869	0·36	0·71
Do.	Broken stone (45 per cent. voids)	902	0·37	0·74
1 : 1½ : 3	Shingle	666	0·41	0·82
Do.	Broken stone (45 per cent. voids)	697	0·43	0·86
1 : 1⅔ : 3⅓	Shingle	610	0·42	0·84
Do.	Broken stone	640	0·44	0·88
1 : 2 : 4	Shingle	520	0·43	0·86
Do.	Broken stone	548	0·45	0·90
1 : 2½ : 5	Shingle	430	0·44	0·88
Do.	Broken stone	450	0·46	0·92
1 : 3 : 6	Shingle	364	0·45	0·90
Do.	Broken stone	383	0·47	0·94
1 : 4 : 8	Shingle	280	0·46	0·92
Do.	Broken stone	294	0·48	0·97

PART II

WORKMANSHIP

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WORKMANSHIP

GRADING

DENSITY in the mass of hardened concrete is essential for maximum strength and watertightness. Voids in concrete mean low strength because of lack of density.

It is therefore necessary to arrange the proportions of different size aggregate so that there are always particles small enough to fill the spaces between the next larger size particles, down to the finest grain of sand. This point is illustrated in *Fig.* 39, which shows a section through a piece of concrete in which there is no fine material to fill the spaces between the larger particles. Such a concrete could be easily crushed and would not be waterproof. *Fig.* 40 demonstrates the result of proper grading; in this case sufficient small particles are present to fill the spaces between the next larger particles. It will be obvious that the more thorough the grading the denser the concrete.

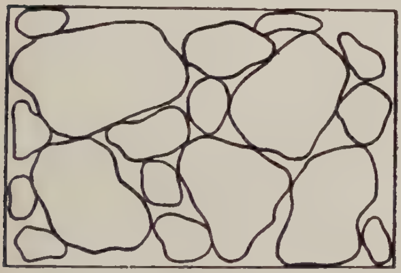


Fig. 39.

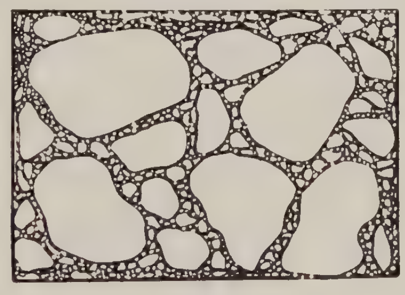


Fig. 40.

The process of arranging a batch of materials for concrete making so that there will be a minimum of voids is known as "grading," and this is one of the most important of the operations in the production of good concrete. For most ordinary purposes a concrete made of 4 parts of coarse aggregate (i.e. material ranging in size from, say, 1 in. down to ¼ in.), 2 parts of well-graded sand, and 1 part of Portland cement has been found to produce a fairly dense concrete, and this mix, known as "4 : 2 : 1 concrete," is often specified. With this proportioning the sand content will approximately fill the voids in the coarse material, and the cement will fill any remaining voids as well as coat all the particles so as to bind them together.

But a rule-of-thumb specification such as this is perhaps not ideal, because the grading of aggregate from no two sources is of necessity the same, and while 2 parts of sand may satisfactorily fill the voids in 4 parts of coarse material in one case, it may be too little in another, and the strengths of the concrete would vary accordingly. To get the same strength with the less well-graded material it would be necessary to increase the cement content, which, in effect, means that cement is being used as a void filler. As cement may cost anything up to twelve times as much as sand, it will be realised that this is a costly procedure, and that it is far cheaper to go to a little trouble to grade the aggregate so that the cement is used only for its legitimate purpose of coating the particles of aggregate and binding them together, and is not used as a void filler when sand would serve the purpose equally well.

Fig. 41.

A simple method of determining the voids in a coarse aggregate is to put half a cubic foot of coarse aggregate in a box, shake it level, and mark the level of the top of the material on the inside of the box. Then, from a previously measured quantity, add dry sand, vigorously shaking the box the while, until no more can be "absorbed" by the coarse aggregate without increasing its bulk. If, say, one-sixth of a cubic foot of sand has been "absorbed" in this way, then maximum density will be obtained by the proportion of 3 parts of coarse aggregate to 1 part of sand.

Various methods of sieving are used to grade aggregates as they come from the pit or river bottom, that is, to separate the mixed material into different sizes. For small batches, hand sieves may be used ; if, for instance, the coarse aggregate is to be from ½ in. down, a sieve with ½-in. openings is used to reject all material larger than ½-in., and the material passing through the ½-in. sieve again sieved with a ¼-in. sieve to separate the sand. The material ½-in. and less is then mixed with the sand in the desired proportions. A hand screen is shown to the left of *Fig.* 41. For large quantities jigging screens (*Figs.* 41 and 42) or revolving cylindrical screens (*Figs.* 43 and 44) are used ; in these cases the holes in various sections of the screen are of different diameters, so that as the material passes over or through them it is graded into several different sizes.

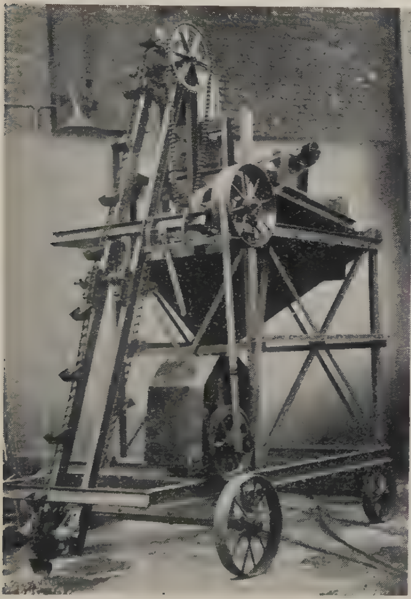


Fig. 42.

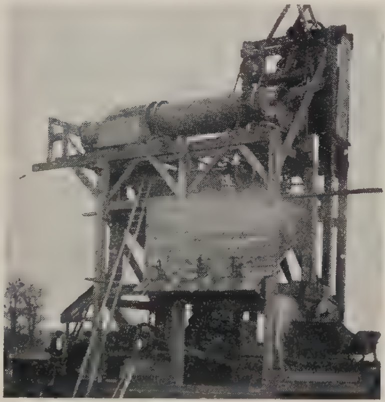


Fig. 43.

As they are won from the pit or river bed, aggregates are often too large for use, and have to be reduced in size by passing through a crusher. Types of crushers are shown in *Figs.* 46 and 47, the former being of the jaw type and the latter a roll crusher. These machines may be set to crush down to any desired maximum size, and the material then passed through screens

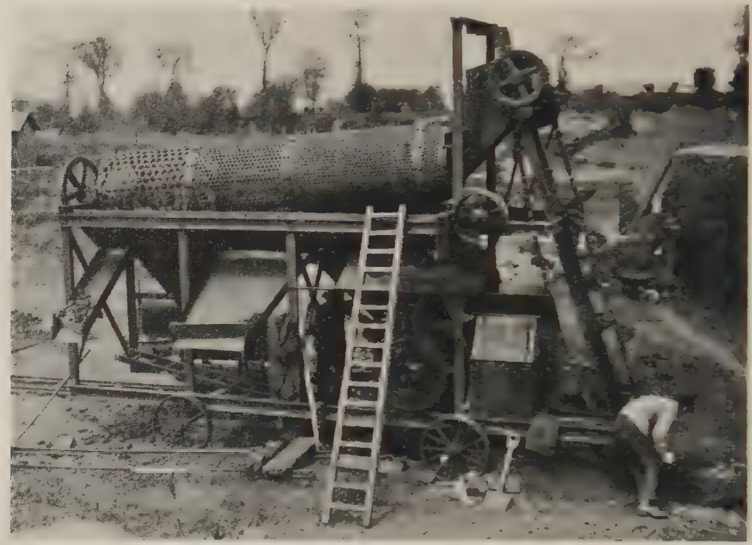


Fig. 44.

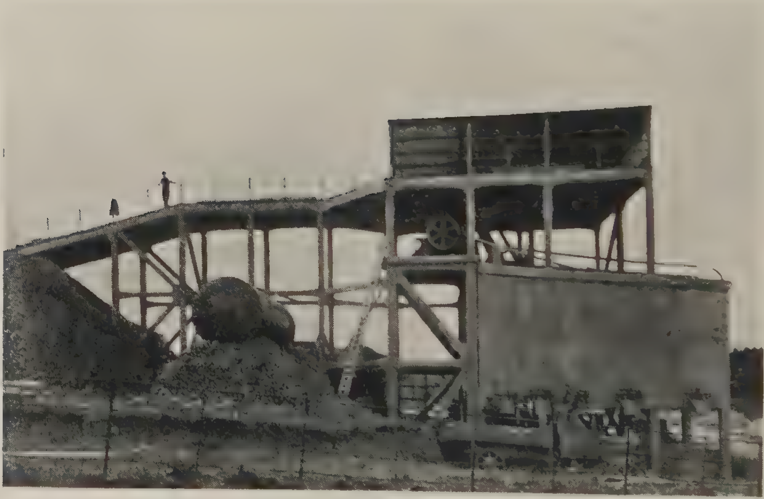


Fig. 45.—A Crushing and Grading Plant.

as already described to grade the crushed material into different sizes and if necessary eliminate any excess of dust.

Grading by "Fineness Modulus."—With the object of putting the grading of aggregate on a scientific basis, Professor Duff Abrams, of Chicago, has evolved what is known as the "fineness modulus" method of determining the proportion of fine aggregate to coarse aggregate to give the most economical concrete mix.

Most aggregates with similar characteristics and the same fineness modulus require about the same amount of water for the same workability, and will produce concrete of the same strength. (The question of water content is dealt with on p. 54.) The object, therefore, is to get as much coarse aggregate in the mix as possible consistent with the necessary workability. Coarse aggregates need less water than fine, consequently the more coarse aggregate the less water required for workability, with the result that the cement content may be reduced without decreasing strength.

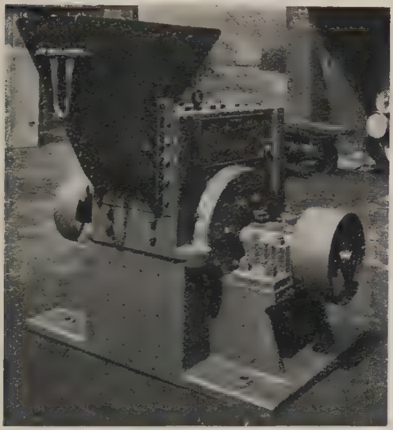


Fig. 46.

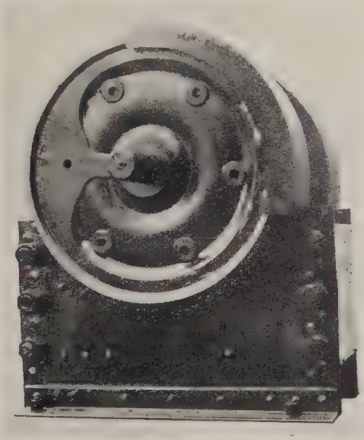


Fig. 47.

Within the range of consistency and workability required in general concrete work, the strength of concrete made with a given proportion of cement will increase as the fineness modulus increases (i.e. as the grading more closely approximates to the ideal) until the mixture becomes too harsh to be workable. This point will be seen to be reached at 5·75 in *Fig.* 48. The fineness modulus of an aggregate is found by adding together the percentages of aggregates left on a set of sieves designed for the purpose and consisting of the following sizes : 100, 50, 30, 16, 8, 4, $2\frac{2}{3}$, $1\frac{1}{3}$, and $\frac{2}{3}$ openings to the linear inch.

A truly representative sample of the aggregates must be obtained for ascertaining the fineness modulus. In the case of sand a sample weighing 6¼ lbs. is used. This is thoroughly shaken through the finest sieve. When convinced that all possible is through, weigh what is left on the sieve, and note the weight in ounces. Do this again with the next sieve, and so on until a sieve is reached that passes all sand after shaking.

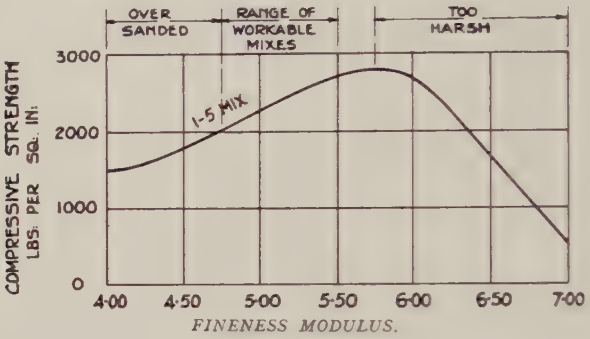


Fig. 48.

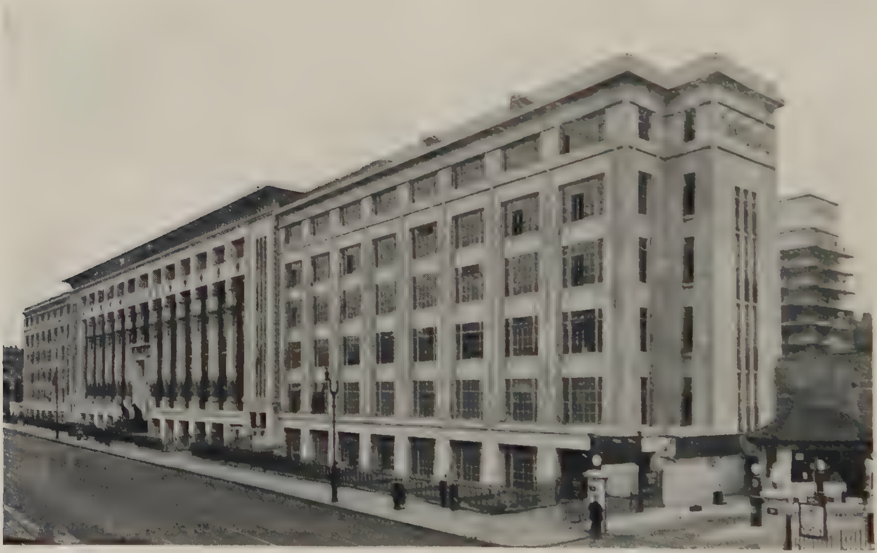


Fig. 49.—Front Elevation of Factory, Hampstead Road, London: Surface Rendered with Coloured Portland Cement Stucco.

Add the weights, place a decimal point two places from the right, and the fineness modulus of the sand is found. For example :

	Ozs.
Sand left on first sieve	80
,, ,, ,, next ,,	65
,, ,, ,, ,, ,,	60
,, ,, ,, ,, ,,	27
,, ,, ,, ,, ,,	25
,, ,, ,, ,, ,,	00
Fineness modulus—	2·57

With the coarse aggregate the method is much the same, but a larger sample is used. Take a representative sample weighing 50 lbs., proceed as with the sand, with the finest sieve first, until all has passed. Weigh what is left on the sieves, but record in lbs. (not ozs.). Do this until a sieve is reached that will pass all the sample. Then add the weights, multiply by two, place a decimal point two places from the right, and the fineness modulus of the coarse aggregate is found.

For example :

	Lbs.
Aggregate left on first sieve	50
,, ,, ,, next ,,	50
,, ,, ,, ,, ,,	50
,, ,, ,, ,, ,,	50
,, ,, ,, ,, ,,	50
,, ,, ,, ,, ,,	50
,, ,, ,, ,, ,,	45
,, ,, ,, ,, ,,	0
	345
Multiply × 2 =	690
Fineness modulus =	6·90

The nearer the fineness modulus is to 5·75 (see *Fig.* 48) the more economical the mix will be ; therefore the fine and coarse aggregates are proportioned so that their combined fineness modulus is 5·75.

Subtract the desired fineness modulus (5·75) from the fineness modulus of the coarse material (6·90), and divide the result by the difference between the fineness modulus of the coarse and fine aggregate (6·90—2·57).

$$\text{Thus } \frac{6{\cdot}90-5{\cdot}75}{6{\cdot}90-2{\cdot}57} = \frac{1{\cdot}15}{4{\cdot}33} = 0{\cdot}26.$$

This gives the proportion of sand to use. In this illustration 26 per cent. of fine aggregate and 74 per cent. of coarse aggregate should be used.

It is thus possible to grade concrete to produce almost perfect density, and although it involves a certain amount of trouble this is repaid in actual monetary gain because of the smaller amount of cement necessary to produce a given strength. Often it is possible to obtain the same strength with an 8 : 1 mix when the materials are properly graded as with a concrete specified to be "4 : 2 : 1" without the knowledge of whether the 2 parts of sand will fill the voids in the 4 parts of coarse material. The time spent on grading would in such a case be rewarded by a saving of about 25 per cent. in the cement bill.

Fig. 50.—Flood-lighted Reinforced Concrete Building near London.

If this "fineness modulus" is ascertained we are able to make use of the tables which have been prepared by Professor Duff Abrams to show the proportioning necessary to obtain the best results from different mixtures.

For aggregates up to a maximum size of 1 in. these tables are as follows:

TABLE 3

PROPORTIONS TO OBTAIN MOST ECONOMICAL CONCRETES

Proportion of Cement to Aggregate.	Size of Aggregate.		
	¾-in. down.	½-in. down.	⅜-in. down.
		Fineness Modulus.	
1 : 3	5·50	5·10	4·70
1 : 4	5·20	4·80	4·40
1 : 5	5·0	4·60	4·20
1 : 6	4·85	4·45	4·05
1 : 7	4·75	4·35	3·96

The "fineness moduli" in this table are the most economical, i.e. a good concrete can be made with less cement than with any other proportioning, and with its use one can ascertain whether any saving can be effected by better grading of the material. If the aggregate now in use has a modulus either above or below that given in the table for a certain size aggregate, it might well repay the trouble of grading it to the fineness modulus which is shown to give the best results. It will be seen, for instance, that the fineness modulus for a 1 : 7 mix with an aggregate ranging up to $\frac{1}{2}$ in. is 4·35, and if the fineness modulus of the material in use differs from this more coarse or fine material may be added until it is obtained.

WRIGLEY'S
LIMITED
WRIGLEY'S

Fig. 51.—Reinforced Concrete Factory at Wembley.

Assuming good materials and uniform workmanship, an increase of 1 per cent. of cement will normally increase the strength of the concrete by 1 per cent. A 1 : 4 mixture thus has approximately twice the strength of a 1 : 8 concrete.

The strength of concrete is, however, intimately connected with the amount of mixing water used, and the statements made above as to the saving in cement consequent upon thorough grading must be taken in conjunction with the following notes on the effect on strength of varying water contents.

WATER CONTENT

It has been definitely proved that variations of water content have a very great effect on the strength of concrete. This effect is so great that with similar aggregates a concrete mixed to a very thin consistency will have only a fraction of the strength of a concrete mixed with the proportion of water that results in maximum strength. Such "sloppy" mixes are never used in practice (except in cementation processes, dealt with elsewhere), but the difference in strength even between a concrete that will flow (as is used in reinforced concrete) and one that contains sufficient water to make it plastic (as is used for mass concrete work) is considerably in favour of the plastic mix; tests show that the plastic mix is 25 per cent. stronger than the wet mix.

Fig. 52.—The Science Museum, South Kensington: A Reinforced Concrete Frame Building.

It is easier to make an apparently well-mixed concrete by adding sufficient water to produce a sloppy mixture than to make a well-mixed stiff concrete, and the sloppy mixture is usually placed into position with less labour than the stiff concrete. But these advantages of excessively wet concrete may be only obtained at the expense of the finished work, because the strength of concrete depends largely upon the ratio of water to cement. After a certain point is reached, the more water that is added to concrete the less is its strength. A concrete of 1 part cement to 8 parts sand and stone, mixed with no more water than is needed to produce a plastic mass, may be as strong as one composed of 1 part cement to 6 parts sand and stone if in the latter case the concrete is made wet enough to flow. Hence, by giving the necessary attention and using more labour to produce a concrete with no more water than is necessary to ensure workability, it is possible to economise in cement. For concrete foundations, roads, and floors without reinforcement, for maximum economy in cement the concrete should be mixed with just sufficient water so that when rammed or punned it combines to form a compact mass. When concrete is required to flow through and under reinforcing bars it must obviously contain more water, and similarly

Fig. 53.—Russell Institute, Paisley: A Reinforced Concrete Frame Building.

when the concrete is elevated to a height and allowed to flow down chutes into position. The necessity for a more fluid concrete being granted, still no more water should be used than the minimum required to produce the necessary fluidity, otherwise there is a risk of the concrete being ruined by segregation of its component parts, i.e. the large aggregate may sink to the bottom of the forms, leaving the mortar on top.

To the builder or contractor on foundation work, concrete floors, and similar constructions it is impossible to emphasise too strongly the fact that whereas more cement per yard of concrete means greater strength, more water per yard of concrete means less strength.

It must be remembered, however, that there is a percentage of water below which there will not be sufficient to hydrate the cement, and the use of too little water, especially in the case of concrete products, has frequently resulted in the production of porous and weak blocks when the makers have been under the impression that they were adopting scientific methods. Too little water is worse than too much.

When using porous aggregate, such as broken brick, clinker, and certain stones, the absorptive properties of the aggregate must be taken into consideration. Water must be present the whole of the period during which the cement is setting, but when porous aggregate is used part of this water will be absorbed by the aggregate, and will thus not be available for keeping the cement in a hydrated condition. When using porous aggregate it is therefore best to soak it thoroughly before use, so that the whole of the added water will be available for its proper function of hydrating the cement.

Slump Test for Consistency

In America the slump test for determining the consistency is strongly recommended, and is generally used there. The only apparatus needed is a sheet-metal truncated-cone-shape mould, 12 in. high, 8 in. diameter at the base, and 4 in. diameter at the top, provided with handles at the sides (see *Fig.* 54), and a ⅝-in. pointed metal rod 1 ft. long. The mould is filled with concrete in layers of 4 in. at a time, each layer being punned exactly 30 times with the rod. After the third and last layer has been punned, the mould is lifted off and the slump measured. Very exhaustive tests recently undertaken show that concrete having a slump of from ½ in. to 1 in. will contain only a little more water than is necessary for maximum strength, but will be too stiff for almost any constructional work ; this is called a consistency of 1·00. An increase of 10 per cent. in the water content will give a slump of 3 in. to 4 in., called a consistency of 1·10 ; an increase of 25 per cent. water gives a slump of 6 in. to 7 in., called a 1·25 consistency ; while an increase of 50 per cent. of water gives a slump of 8 in. to 10 in., or a consistency of 1·50. *Fig.* 55 shows the relation between the slump in inches and the strength of concrete made with " Ferrocrete " rapid-hardening Portland cement.

The test should be applied to a portion of the first batch of concrete that is mixed, and if the slump is not in accordance with the specification the quantity of water should be altered and the slump again measured, repeating the same procedure if necessary. Having arrived at the correct consistency, the test should then be applied several times per day to ensure that the required consistency is uniformly maintained.

A competent inspector or foreman can easily control the quantity of water and, therefore, the strength of the resulting concrete. Each excess pail of mixing water may decrease the strength of concrete as much as if two pails of cement had been left out. The quantity of mixing water must be kept as small as practicable for the class of work being undertaken. The same consistency should be used in all batches, and care must be taken to ensure that the concrete being tested is not caused to slump by vibration of the board on which it is turned out of the mould.

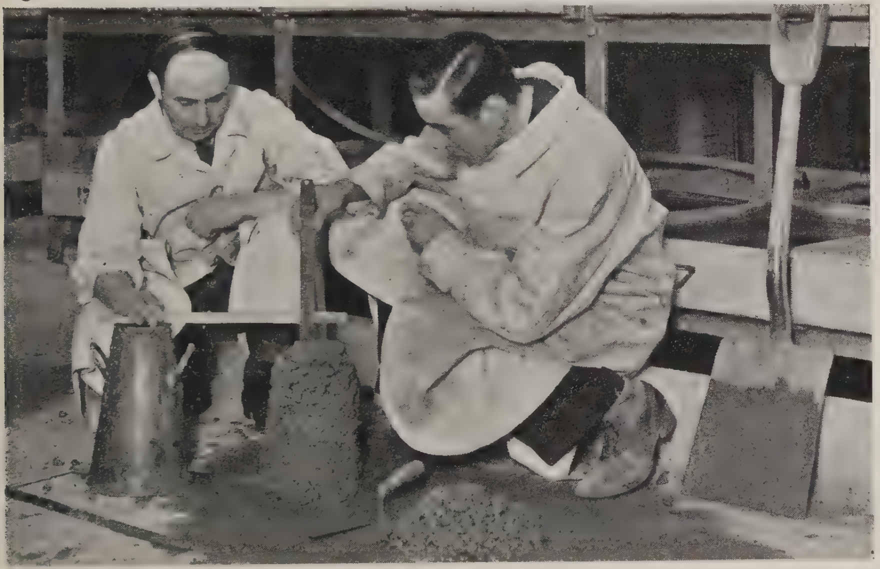


Fig. 54.—Making the "Slump Test."

The following slumps are recommended for different types of concrete:

Class of Concrete.	Maximum Slump (ins.).
Mass concrete	2
Reinforced concrete—	
Thin vertical sections	6
Heavy sections	2
Thin confined horizontal sections	8

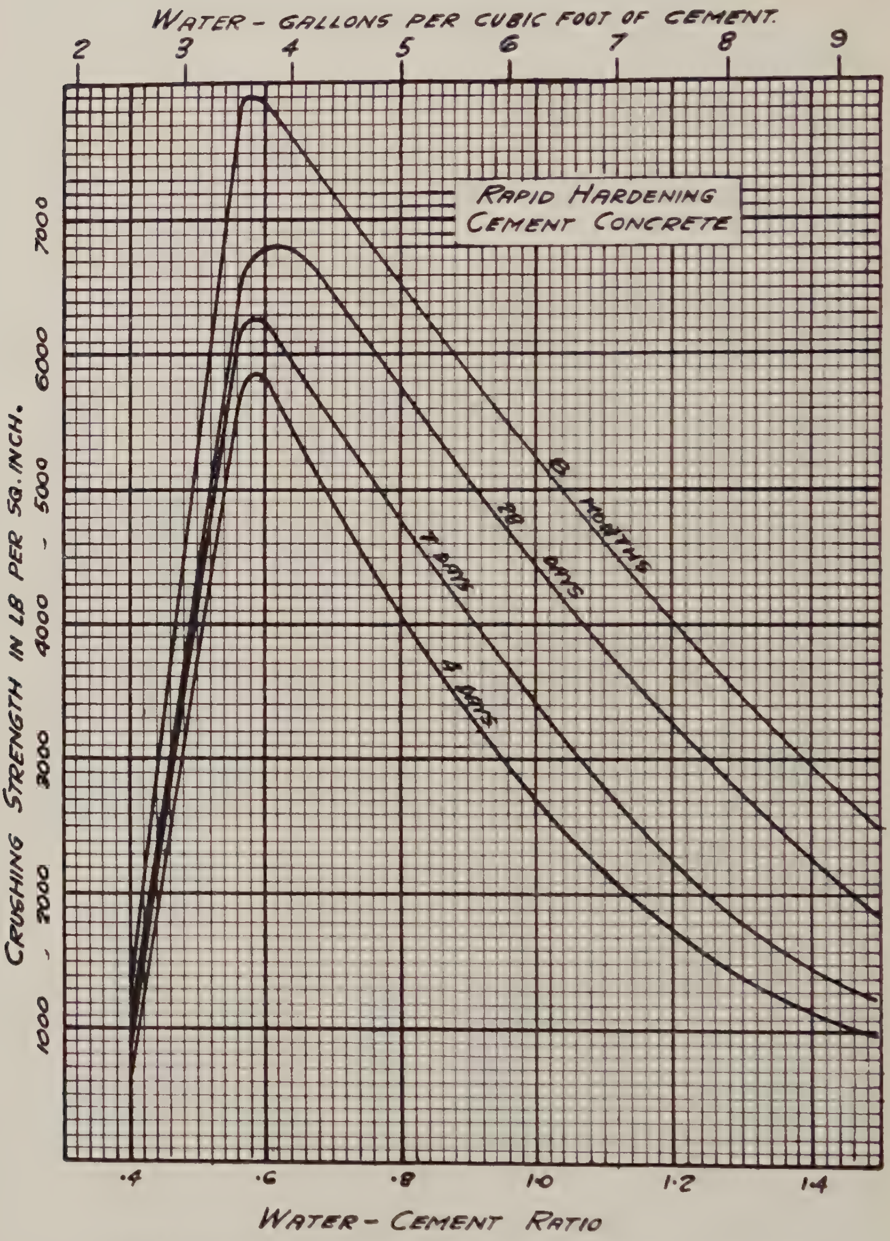


Fig. 55. -Relation between Water-Cement Ratio and Strength.

Class of Concrete.	Maximum Slump (ins.).
Roads and pavements—	
Hand finished	4
Machine finished	1
Mortar for floor finish	2

Quality of Water

Contaminated or impure water may seriously reduce the strength of concrete, and although some impure waters have less deleterious effect than others it is a good rule to use only clear water. Most water that is fit for drinking purposes is suitable for concrete making.

Sea water may be used, but it has a slight retarding effect upon the setting of the cement.

MIXING

The function of cement is, of course, to bind together the loose aggregate to form concrete, and it will be realised that for maximum strength every particle of stone and sand should be thoroughly coated with cement so that every particle is firmly cemented to those surrounding it at every point of contact. To achieve this object thorough mixing is essential.

The mixing of concrete should be thorough; this is as important as proper proportioning and good materials. All ingredients should be carefully measured or weighed. A convenient form of measure for the sand and broken stone is a box without top or bottom (*Fig.* 56). The cement should be taken by weight, though the size of the measures used for the coarse material can be so adjusted as to permit a sack or cask of the cement to be taken as the unit for that material. The sack of cement, ten, eleven, twelve or twenty to the ton, is a convenient unit if the batches are large enough for a whole sack of cement. It is a convenient practice to base the proportions on a sack of cement, that is, the concrete is measured in cubic feet of coarse aggregate and cubic feet of sand to a bag of cement. A wheel-barrow of known capacity is another unit of measure on small jobs.

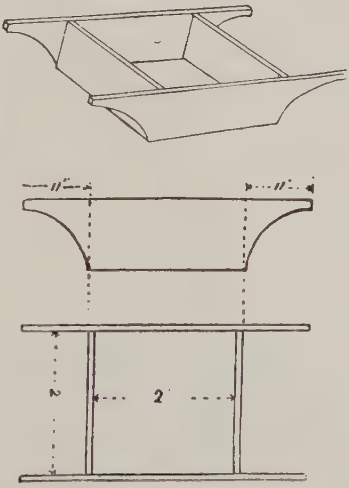


Fig. 56.—Bottomless Measuring Box.

For small boxes the handles are not necessary.

On larger contracts common practice is to elevate the sand and gravel into bins, one bin for the coarse aggregate and one for the fine material, with gates at the bottom of the bins to control the flow of materials into the mixer or measuring devices.

Water may be measured by a watering can when hand mixing is adopted. To use a hose requires some little experience and care on the part of the person handling it lest the Portland cement and sand be washed away from the coarse material; moreover the water cannot be measured when hosed on.

The concrete should be mixed as near to the place where it is to be used as practicable, for if left standing for any length of time it may set and become useless. No concrete which has set should be allowed to be broken up and used unless it is treated as a coarse material and mixed with a fresh proportion of Portland cement.

Hand Mixing.—If mixing is to be done by hand the measured materials should be spread out on a wood platform closely jointed and fitted with ledges around the sides to prevent waste of materials. If much mixing is to be done the board may be covered with sheet metal, or a concrete floor may be laid for the purpose.

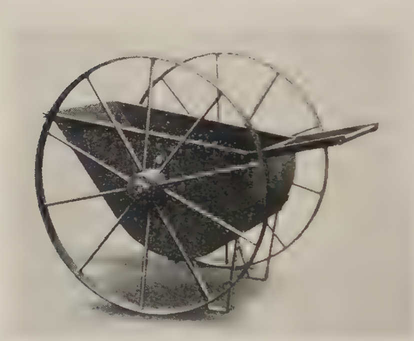


Fig. 57.—Concrete Cart.

The coarse material should be measured first. The sand should then be measured and spread in a layer of even thickness over the coarse material. The Portland cement should next be distributed over the surface of the sand, and the whole turned over dry with the shovel until the materials are seen by their uniform colour to be thoroughly mingled. Then the whole should be turned at least three times dry and three times after wetting. It is better to add the water a little at a time, until the right consistency is obtained, than to throw it on all at once. The best method to apply the water is by means of a watering-can of known capacity with a rose head. *Fig.* 58 shows the process of hand mixing.

Machine Mixing.—In all cases where the output warrants the cost machine mixing is to be preferred, as the results are more uniform. There are several different types of mixers, namely, the revolving drum type (*Figs.* 59 and 62-67), the open trough type (*Fig.* 60), pan mixers (*Fig.* 61), and continuous mixers. So far the continuous mixer (in which the materials are fed separately into one end of a cylinder, mixed while travelling along it, and emerge in a continuous flow of mixed concrete at the other end) has not generally been favourably received, and the batch type is preferred.

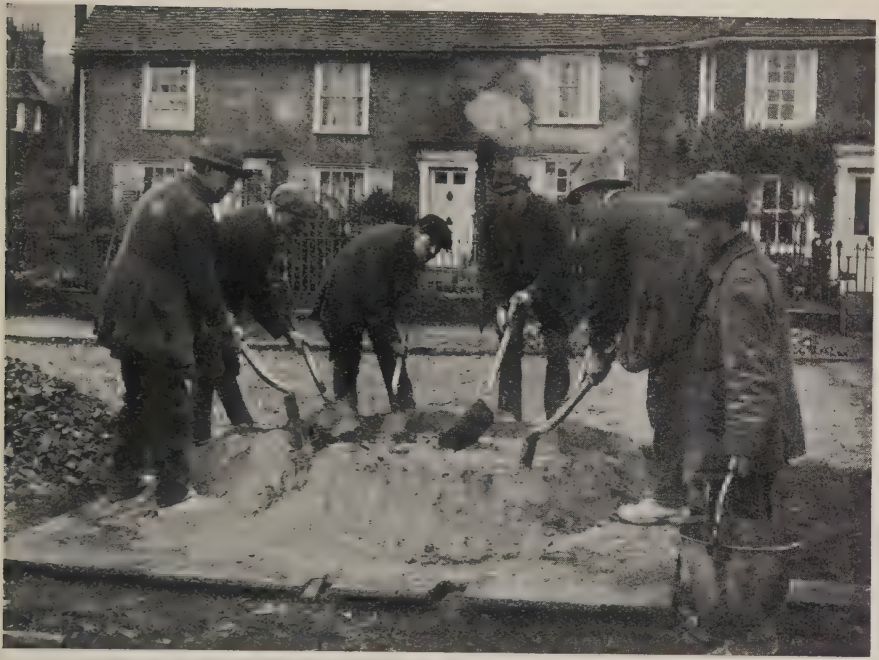


Fig. 58.—Mixing by Hand.

These machines are supplied in sizes with batch capacities of 3 or 4 cu. ft. up to 2 cu. yds.

The smaller sizes may be operated by hand or power, and may be purchased (for hand operation) at prices from £20 and upwards. Most machines may be obtained mounted on a truck with road wheels for easy transportation (*Figs.* 59–60, 62–67) or on a stationary base (*Fig.* 61). Usually the larger mixers are provided with a power unit, either a petrol engine or steam boiler mounted on the same truck with the mixer, but nearly all mixers are supplied adapted for belt drive by electricity or other form of power.

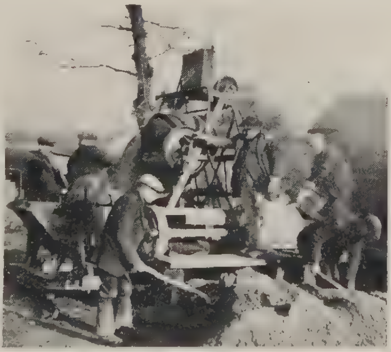


Fig. 59.

Modern mixers of the larger sizes are generally fitted with automatic water supply by means of an overhead tank (see *Figs.* 59, 64, 66, 67), which may be connected with the mains, and containing a ball-cock or other device

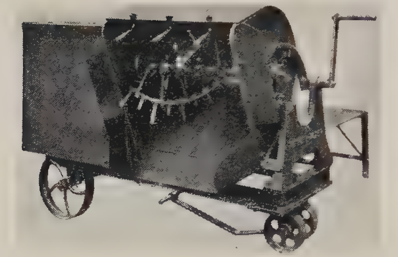


Fig. 60.

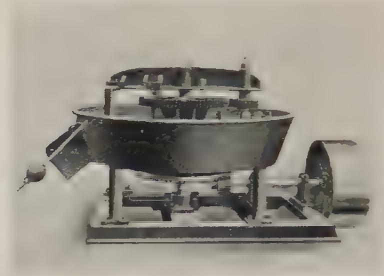


Fig. 61.

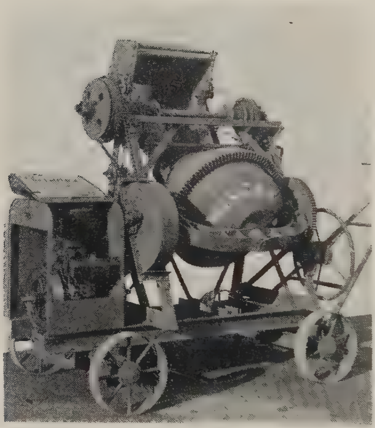


Fig. 62.

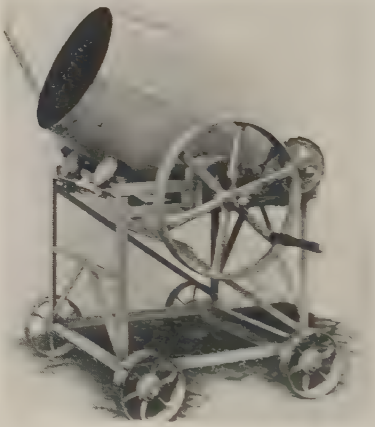


Fig. 63.

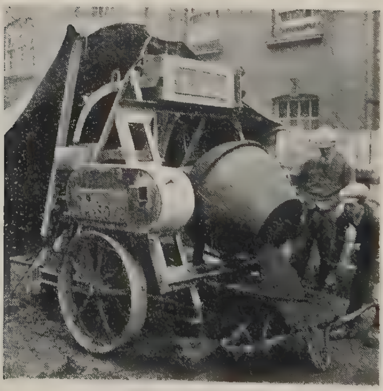


Fig. 64.

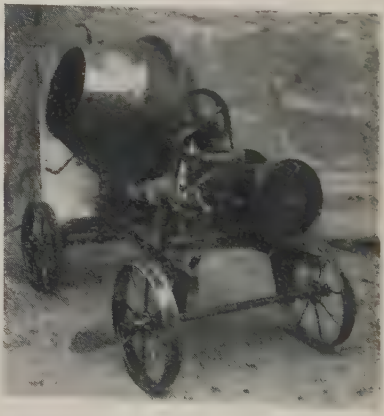


Fig. 65.

by which the pre-determined amount of water per batch may be fixed by the works superintendent so that it cannot be departed from without his knowledge.

Charging hoppers (seen in some of our illustrations) are also generally provided for feeding the drum, or the materials may be delivered to the mixer through overhead hoppers, by shovel, or by running barrows up an incline and tipping into the drum.

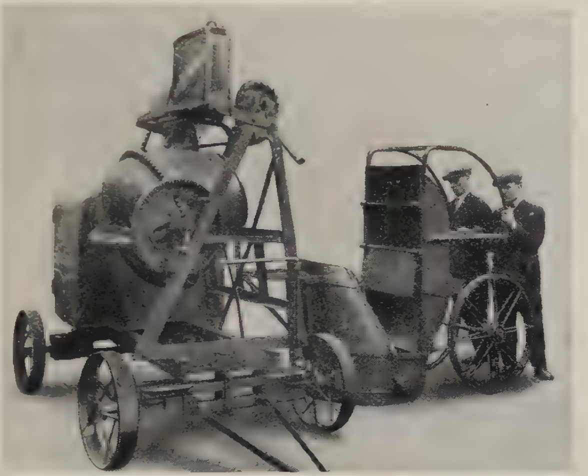


Fig. 66.

Whichever method is adopted the correct quantities should be delivered for each batch, and care must be taken to ensure that the barrows are completely emptied, or the platform cleared, after each mix; failure to do so will alter the proportioning, and therefore the strength of the concrete.

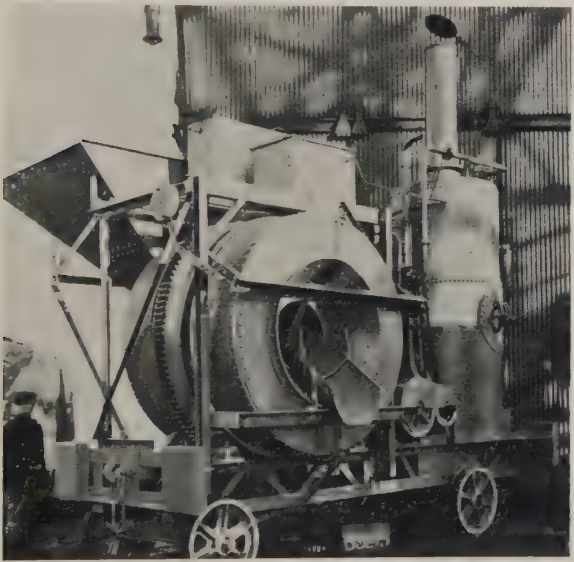


Fig. 67.

The best practice is to put the materials into the drum and mix them dry until they are of uniform colour, then add the water (while the drum is still revolving) and continue mixing until the whole is thoroughly mixed before discharging.

If the machine is not fitted with a tank and water measuring device, an ordinary flushing tank makes a good substitute which will deliver the same quantity for each batch. For preference the water should be fed into the drum through a perforated pipe to distribute it evenly over as much of the contents as possible. On some of the latest types of machine the period of mixing is automatically controlled.

Sometimes the mixed materials are deposited in the moulds or forms by a chute (*Fig.* 99). In such cases care must be taken to regulate the slope of the chute so that the materials do not become separated on their way from the mixer to the forms, as if this happens all the care taken in mixing will be wasted and a weak concrete result.

For road work an arm along which a bucket runs is often used in conjunction with the mixer (see *Fig.* 68); the mixer-drum empties into the bucket which dumps the batch where required.

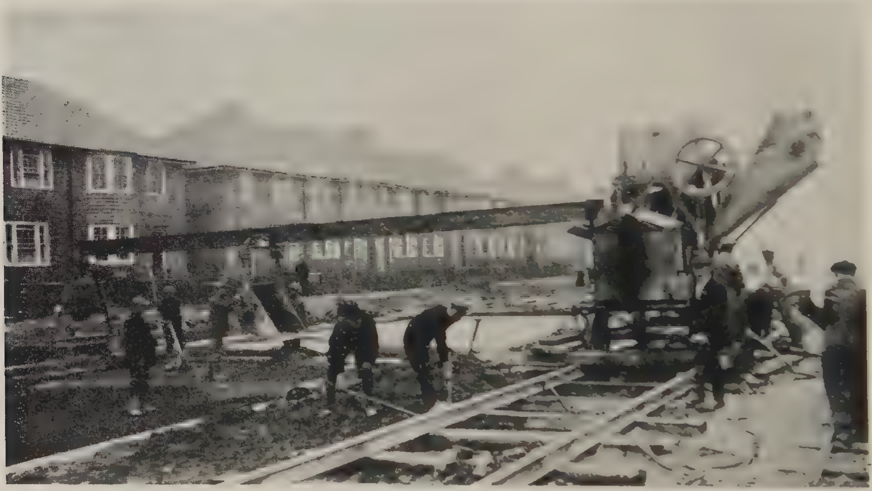


Fig. 68.

Period of Mix.—No definite period of mixing can be laid down, as the number of drum revolutions per minute varies with different machines, but trial batches may be mixed until uniformity is obtained and subsequent batches mixed for the same length of time.

Thorough mixing not only increases the workability of the concrete—an important point when the concrete is made semi-dry—but also very considerably increases its strength. For instance, 28-day tests on concrete mixed for one minute and two minutes show an increased strength of over 30 per cent. in favour of the longer period. Mixing for further periods up to ten minutes has but little effect on the strength above that obtained with a two-minute mix. The effect of varying periods of mixing is shown in *Fig.* 69. The greatest increase in strength is imparted to the concrete between one and two minutes after the water is added, and no concrete should be mixed for a less period than 1½ minutes.

Recent investigations have shown that so long as mixed concrete is prevented from stiffening by occasional stirring up, and also prevented from losing water by evaporation, it can be kept for as long as three or four hours in a plastic state with no disadvantage. This is a convenience in cases of central concrete mixing plants on road jobs where the mixing plant is set up in one position and the mixed concrete conveyed by lorry or otherwise to the job. In some cases the idea of central mixing plants is developed to the extent of having mixing gear on the lorry itself to give the concrete the agitation it needs to prevent separation.

Care must be taken to discharge the whole of the contents of the drum with each batch, and at the end of each day the drum should be thoroughly washed out. Any tendency of the concrete adhering to the drum, and refusing to leave it when the drum is tilted, can be prevented by coating the plates with a thin film of mould oil.

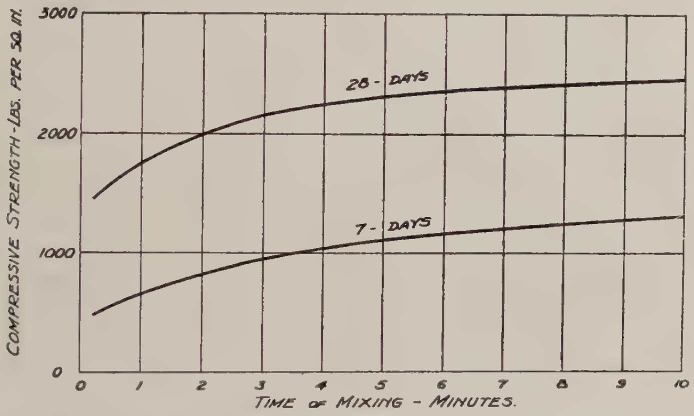


Fig. 69.—Effect of Period of Mixing on Strength of Concrete.

Generally, no more concrete should be mixed than is immediately required, as it must be placed before the initial set of the cement commences. The British Standard Specification for Portland cement prescribes a period of thirty minutes between the time of adding water to the cement and the initial set; this is laid down as a minimum period, and although the initial set of cement may sometimes be postponed for a longer period it is as well not to take risks, and to place the material in the moulds or forms within half-an-hour of mixing.

Mixers must be cleaned free from Portland cement before charging them with aluminous cement, as mixing of the two may result in very rapid setting, or failure to set. The two cements must not come in contact with each other during storage, for the same reason.

REINFORCEMENT

Purchase of Bars.—As soon as the detail drawings of the structure have been completed the steel is taken off and a list made of the bars of each diameter required. The list will contain the number and lengths of each size of bar. A copy of this list is then sent to the rolling-mill for a quotation and date of delivery. If the job is only a small one and the total amount of steel is less than four tons it must be remembered that carriage will be charged on a minimum weight of 4 tons. In case the mills are not able to supply the bars by the required date they may be ordered "ex stock," but this entails an extra of £1 per ton.

It is important not to make an enquiry for short lengths, as bars less than 5 ft. long are charged 5*s*. a ton extra and bars less than 3 ft. in length carry an extra of 10*s*. per ton. This extra can be avoided by ordering the bars in multiples of the length required and cutting them on the site. The "basis price" quoted by the mills is for ⅝-in. bars and extras of 20*s*. and 50*s*. a ton are charged for ⅜-in. and ¼-in. bars respectively.

In addition to the bars, No. 16 S.W.G. mild steel wire will be required for tying the intersections.

Stacking.—Bars are delivered in bundles of the different diameters and should be stacked on the site in a way which prevents them from getting covered with mud or rusting and enables the foreman bender to find the various lengths easily.

Cutting and Bending Bars.—For small bars a bolt-cropper is generally used, larger sizes requiring a cold chisel, hacksaw or power-driven shearing machine.

A bar-bending schedule is supplied to the foreman showing the shapes to which all bars are to be bent. For bending, bars may be divided into five classes :—

(1) Long stirrups or links such as are used in fence posts, tank walls, etc.
(2) Hoops for columns, piles, etc.
(3) Beam stirrups.
(4) Bars with two or more cranks, and hooks for slabs and beams.
(5) Column or pile bars which only require slight offsetting at the end.

Class (1) is most easily bent by a device such as is shown in *Fig.* 70. Other bars may be bent round pins fixed in a heavy timber balk set at a convenient height above ground level and using a piece of gas-pipe fitting over the end of the bar as a bending-lever. A bench with 2-in. or 3-in. thick top is preferable to a balk in many cases, as the bench may be made of any desired width. Various makes of bar-benders are on the market, such as those shown in *Figs.* 71 and 72. Heavy bars require the use of a power-bender. It is best to bend bars without heating, but this is not always practicable, especially when hooks of small diameter are required on heavy steel.

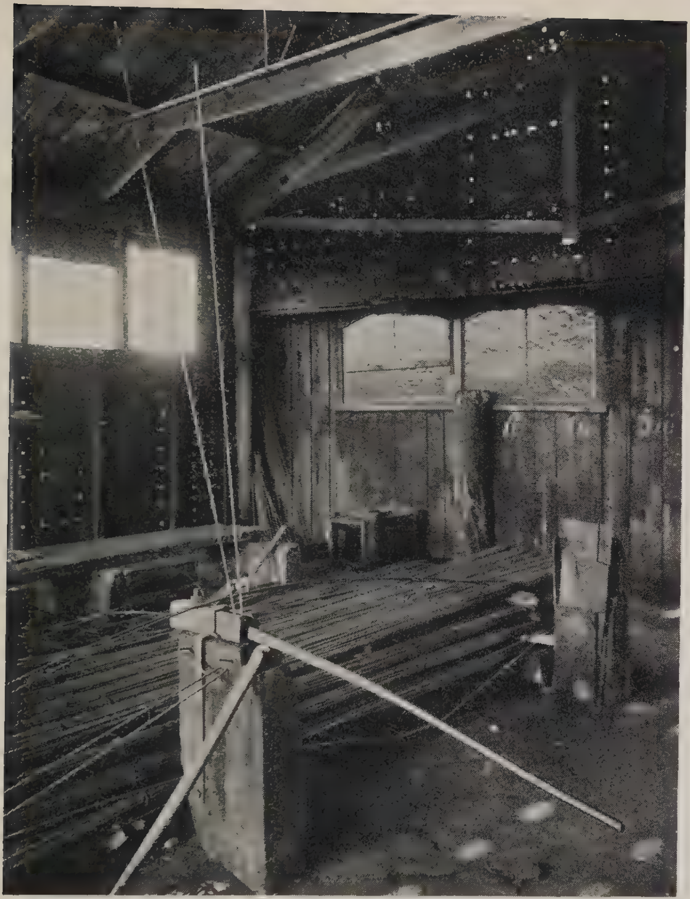


Fig. 70.—Bending Reinforcement.

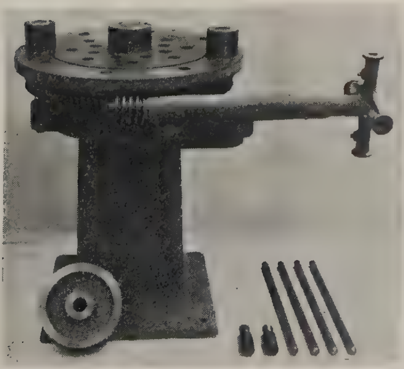


Fig. 71.

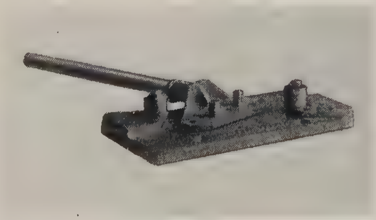


Fig. 72.

As a general rule hooks should be bent round a mandrel whose diameter is four times that of the bar to be bent.

Bars to act as hooping reinforcement for circular tanks, etc., are best bent in a hooping machine, as it is important that the bend should be truly circular.

Fixing.—So far as possible the steel should be assembled into frames on the bench and wired before being erected in place. A convenient method of assembling frames for columns and beams is shown in *Fig.* 73. Where column steel is erected *in situ* some form of spacer (*Fig.* 74) helps to hold the vertical bars in position. If long vertical bars of small diameter are to be used in walls, these may be prevented from getting out of place or swaying by the arrangement shown in *Fig.* 75.

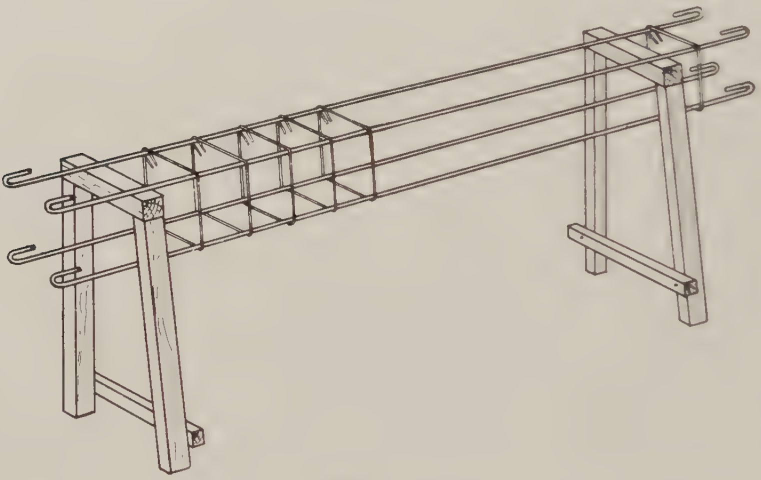


Fig. 73.

Bar-fixing in slabs is rendered easier by the use of special chairs or by boards cut as in *Fig.* 76. In order to keep the bars at the correct distance from the bottom of the slab, pre-cast concrete blocks have been used in some jobs. Intersections of bars should be wired on the " under and over " principle shown in *Fig.* 77, which ensures a rigid joint.

The lengths of laps required will depend on whether the bar is in tension or compression, the usual amount being 40 diameters for tension and 20 diameters for compression.

Supervision.—Too much attention cannot be given to placing the steel, since errors will upset the most careful design and may result in unsightly cracks or even failure of the structure. The substitution of a $\frac{3}{8}$-in. bar for a $\frac{1}{2}$-in. one may not seem a very serious matter, but the area of the former is little more than one-half that of the latter and therefore it can only take

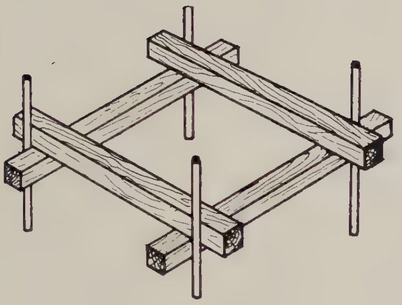


Fig. 74.

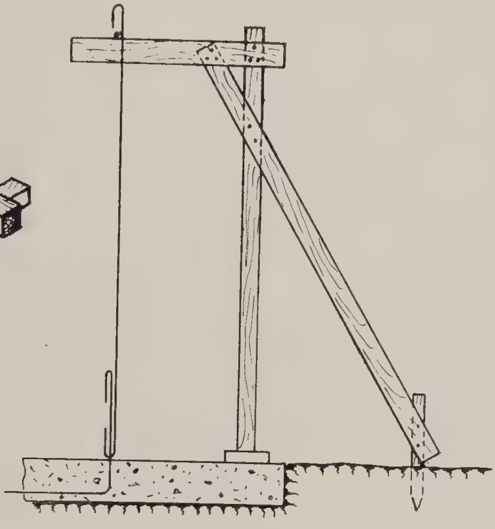


Fig. 75.

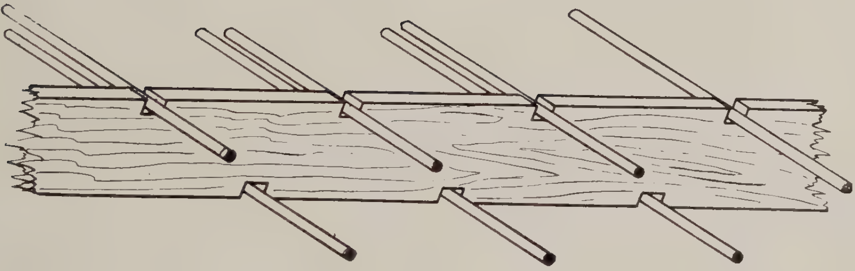


Fig. 76.

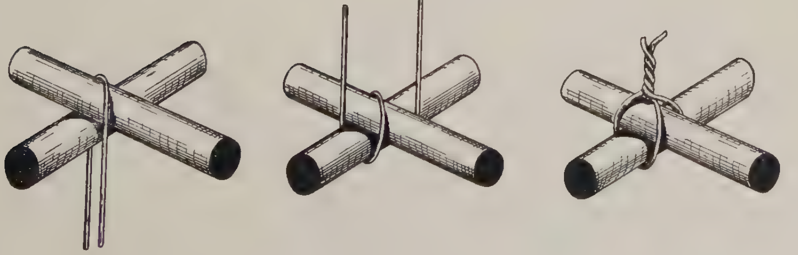


Fig. 77.

one-half the load required to be carried. Such an error is just as serious as if one were to cut away half the bottom flange of a rolled steel joist and expect the remainder to carry as much load as an undamaged joist.

Fortunately supervision is made easy in reinforced concrete work by the constant repetition of the same steel in each floor panel, beam, or column, on any floor. Another point to be watched is that the bars have the amount of cover mentioned on the drawing; if this is not done rusting may commence and lead to flaking off of the concrete and further exposure of the steel to the atmosphere, or the beam may not have the strength required owing to the lever-arm being diminished. Provided that the bars have been bent accurately it is an easy matter to ensure that the cover is correct.

Patent Meshes.—These are mostly used for slabwork, footings, and walls. Owing to the small cross-section of the strands they may be cut by a bolt-cropper. Bends are either pulled round or made on an anvil for the heavier sections.

The laps must be not less than specified on the drawings, and care must be taken that the bends where the reinforcement rises to the top of the slab are properly made. Under no consideration should the reinforcement be allowed to sag down by its own weight from the top of the slab, over the beams, to the bottom at midspan of the slab. Where fabrics are used in footings or roadwork they should be placed on a layer of plain concrete and not directly on the excavation. If the latter is done the steel will rust away with time. The practice of bending slab bars in position is not recommended.

When placing fabric care must be taken to lay it in such a way that a section at right angles to the direction in which the slab spans contains a greater area of steel per foot width than a section taken in the direction of the span.

Drawings showing a selection of patent reinforcing systems are given in *Figs.* 78 to 83, as follows:

B.R.C. Fabric.—This is supplied with square or rectangular mesh and also as top and bottom reinforcement (*Fig.* 78). The former may be obtained either in rolls or in flat sheets up to 17 ft. in length.

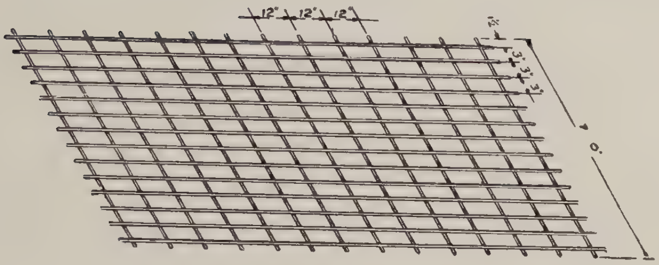
B. & T. Reinforcement (*Fig.* 79) is manufactured from square twisted rods in flat sheets. A double layer reinforcement is also supplied.

Maxweld Fabric (*Fig.* 80) is a mild steel mesh, having a high tensile strength. It is supplied in rolls.

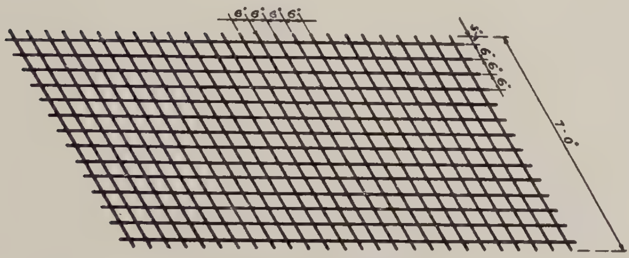
Expamet is manufactured from mild steel sheets which are cut and then expanded into a mesh. The double reinforcement is shown in *Fig.* 81.

Walker-Weston Reinforcement (*Figs.* 82 and 83) is made as (1) single layer, (2) double layer with vertical shear members and (3) interlocked pyramidal double layer and assembled in mats up to 40 ft. by 40 ft. Either mild or drawn steel may be used.

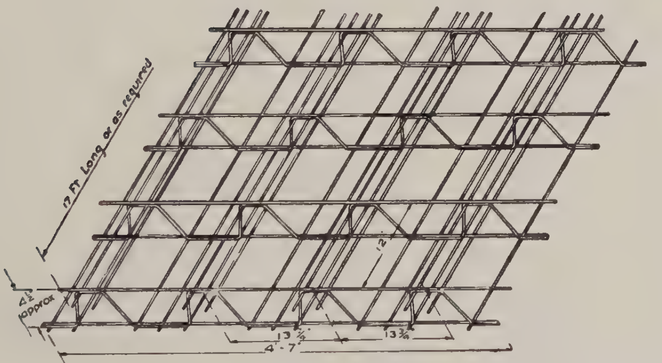
Self-Sentering Expanded Metal is made in three forms known as (1) Self-


12"
12"
12"
1½"
3"
3"
3"
7' 0"

Longitudinal Mesh.


6"
6"
6"
6"
3"
6"
6"
6"
7'-0"

6-in. Square Mesh.


17 Ft Long or as required
4½ approx
12
13½
13¾
4'-7"

Top and Bottom Reinforcement.

Fig. 78.

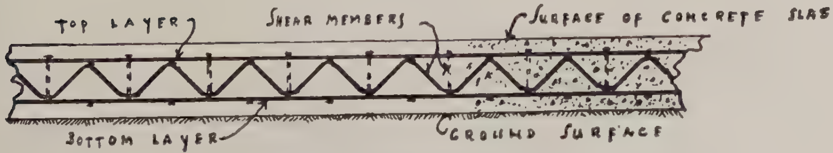

TOP LAYER
SHEAR MEMBERS
SURFACE OF CONCRETE SLAB
BOTTOM LAYER
GROUND SURFACE

Fig. 79.

Sentering, (2) Trussit, and Double Mesh Herringbone. The latter is used for curved suspended ceilings.

Hy-Rib, supplied by the Trussed Concrete Steel Co., Ltd., is a steel lathing of great rigidity which acts as both centering and reinforcement.

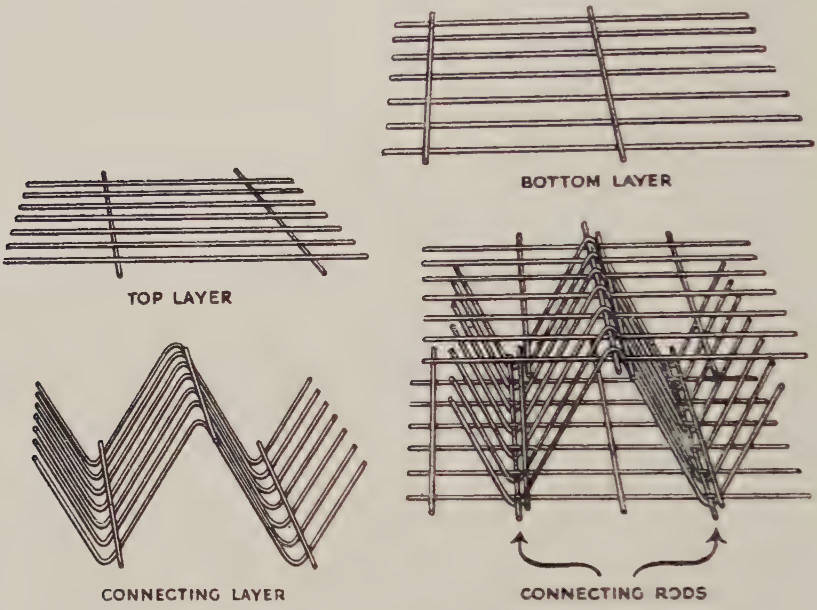


Fig. 80.

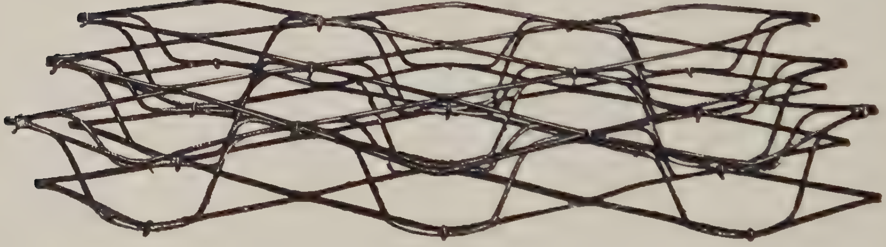


Fig. 81.

FORMS

Timber.—The most easily obtainable timber for form work is pine, either Norway or American Southern pine, which is available in all sizes and is easily worked and cheap in comparison with other woods. Where strength is required, particularly in the larger size timbers, there is no wood equal to American pitch pine or Southern long leaf pine. When it can be obtained spruce is one of the best timbers for all-round use. Hemlock is not desirable, as it is coarse grained and liable to curl. Fir is now being used to some extent in America, and Douglas fir timbers are almost equal to long leaf pine.

Freedom from knots and coarse grain is desirable, as these will show on the finished concrete, for which reason soft white pine is one of the best timbers to use for mouldings, cornices, bridge parapet walls, etc., where an extra smooth finish is required. Soft white pine is, however, too expensive and has too little strength for form timber generally. Hardwoods are not used for formwork except as caps and wedges under or over posts, where they are used to increase the allowable compression across the grain and so often allow a smaller post to be used. Hardwoods are difficult to work and nail.

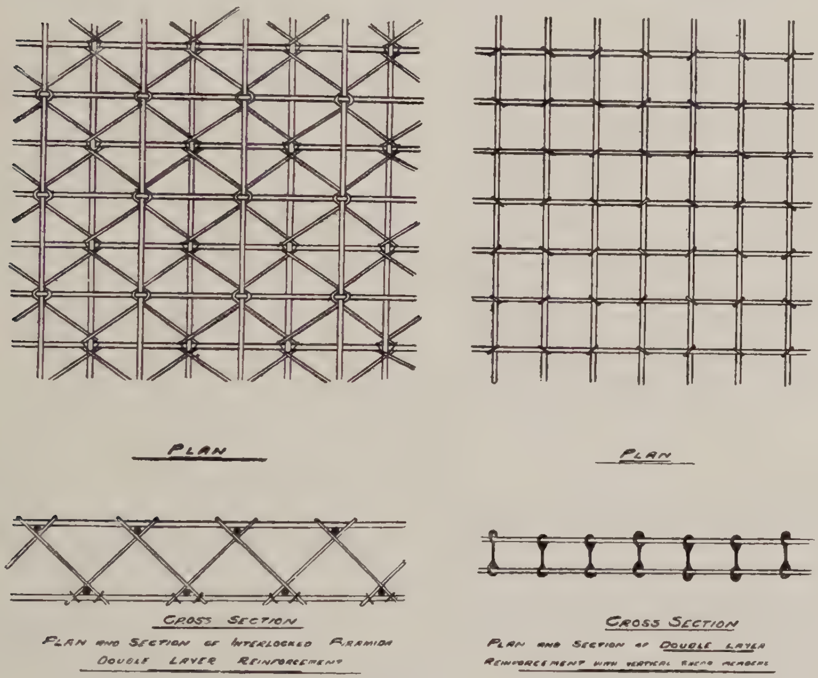

PLAN
PLAN
CROSS SECTION
PLAN AND SECTION OF INTERLOCKED PYRAMIDA DOUBLE LAYER REINFORCEMENT
CROSS SECTION
PLAN AND SECTION OF DOUBLE LAYER REINFORCEMENT WITH VERTICAL SHEAR MEMBERS

Fig. 82.

Partially seasoned timber is the best for formwork, as if it is too dry it will tend to swell from absorption of moisture, while green timber will tend to dry out and shrink in hot weather, causing fins and ridges on the concrete.

Timber may be rough or dressed. It may be dressed in various ways, such as all four sides, one side and one edge, one side and two edges, etc. Usually it is best to use timber dressed on all four sides, as it will then be of more uniform size and is more easily adaptable for different purposes. Wood of any one size should be dressed to a uniform thickness, so that the pieces will match up; this is particularly important with sheathing, as otherwise labour will have to be spent planing down the joints. Joists and studs, too, if they are not of uniform thickness, will cause considerable trouble in fitting.

Sheathing, 1 in. to 2 in. thick, may be tongued-and-grooved, square, or bevelled edge. Tongue-and-groove gives the best results, while a bevelled edge is good if the wood is very dry, as when built up it will not buckle so easily when swelling. Square-edged timber is generally used in the heavier thicknesses.

Thicknesses of timber will depend on the available supply and the loads to be carried, but more often on the former, as any ordinary size can be used to advantage by adjusting the spacing of the supports.

In general, for floor sheathing, 1 in. dressed down to $\frac{13}{16}$ in. is the usual practice; for wall sheathing and beam and column sides the thickness may vary from 1 in. to 2 in. stock dressed $\frac{3}{16}$ in. or $\frac{1}{4}$ in. Beam bottoms are generally 2 in. stock.

Joists may be any size from 2 in. by 4 in. to 3 in. by 10 in., 2 in. by 6 in. being the commonest size; column yokes are usually 3 in. or 4 in. by 4 in. Studs and wales vary from 2 in. by 4 in. to 6 in. by 6 in.; posts from 3 in. by 4 in. to 6 in. by 6 in. In ordinary work the smaller sizes mentioned above are used, extra strength being obtained by doubling up.

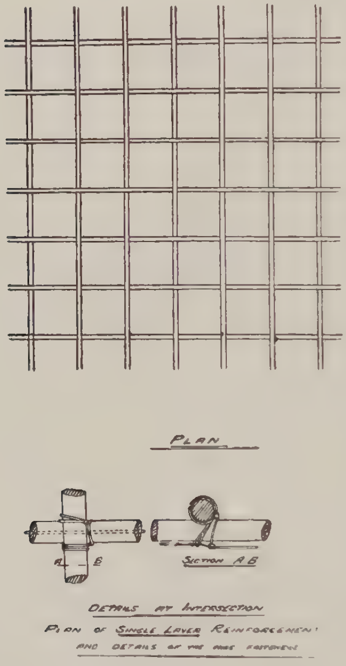

PLAN
A
B
SECTION AB
DETAILS AT INTERSECTION
PLAN OF SINGLE LAYER REINFORCEMENT
AND DETAILS OF THE WIRE FASTENING

Fig. 83.

The lengths of timber ordered, when this can be specified, should be such that they can be used to the best advantage, with the least waste, a point which is often overlooked. Sheathing can be ordered in random lengths, as it generally has to be cut up and short lengths can always be worked in. Joists, studs, posts, beam bottoms, etc., where exact dimensions have to be met, should be ordered the nearest commercial length to the height or span required. If floor joists, for instance, are to span 5 ft. 6 in.

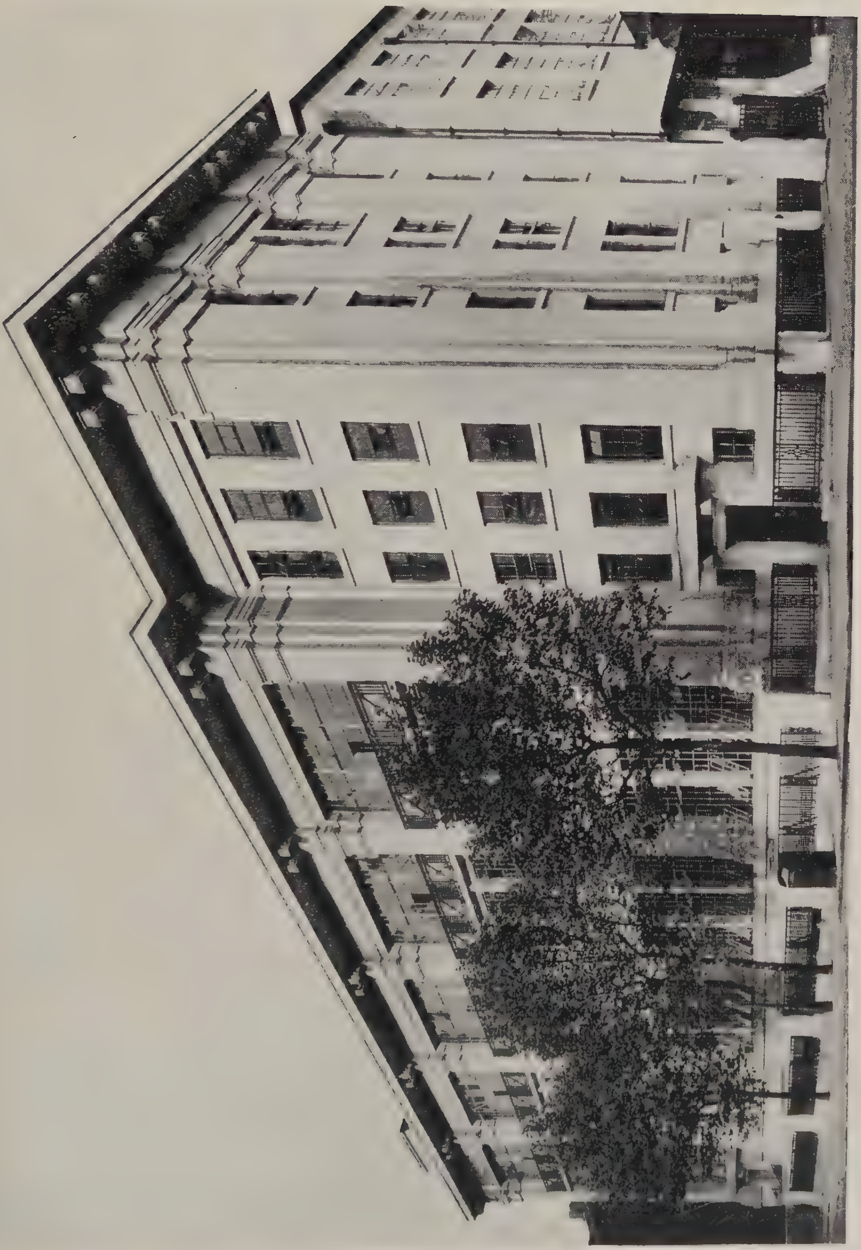


Fig. 84.—New Letter Sorting Office at Mount Pleasant: Reinforced Concrete Frame Building.

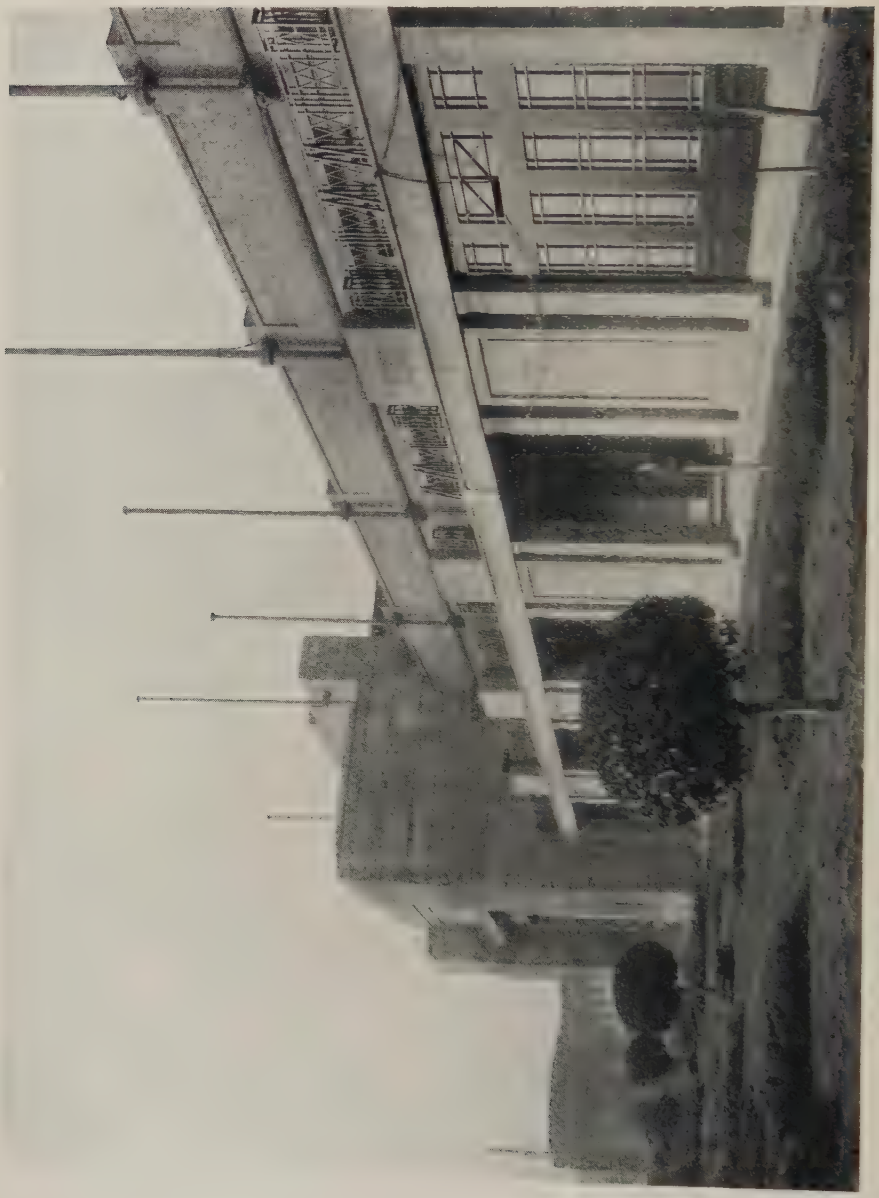


Fig. 85.—Reinforced Concrete at the British Empire Exhibition.

they should be ordered in 12-ft. lengths for the least waste. Care in specifying the lengths is important, otherwise there will be a lot of short ends and surprising percentage of waste. Timber cost is a big item in reinforced concrete construction, and the material should be ordered with care.

Common wire-cut steel nails are used, the most general sizes being *6d.*, *8d.*, *10d.*, and *20d.* Double-headed nails, if they can be obtained at a reasonable price, are an advantage as they can be drawn easily.

Tie wire for tying wall forms may be either number 8, 9 or 10 black annealed wire, number 9 giving the best service for ordinary work. Steel or galvanised iron wire should not be used, as it is brittle, hard to handle, and too springy.

Bolts with washers and nuts are generally used in heavier wall construction in sizes from $\frac{1}{2}$ in. to $\frac{3}{4}$ in., usually with square heads and nuts. If they are to be drawn after use they should be well greased or fitted with sleeves.

All forms coming in contact with the concrete, if the concrete is not to be plastered, should be well oiled or greased to allow easy stripping and to prevent concrete adhering to and coming away with the forms. If the concrete is to be plastered the plaster will adhere better if the surface is rough. Special non-staining oil, made for the purpose, is the best to use, though soft soap and water is satisfactory.

Loads.—The load to be carried by formwork is the weight of the wet concrete and the forms themselves and a live load which allows for impact, wheeling over the forms, etc., and is therefore a construction load. The weight of the forms can be neglected, as it is small compared with the other loads.

To simplify calculations, the weight of concrete may be taken as 144 lbs. per cubic foot. It is then only necessary to multiply the thickness of a floor by 12 to get the weight per square foot, or to multiply the depth and width of a beam together to get the weight per lineal foot. For instance, a 5-in. slab will weigh 60 lbs. per sq. ft., and a beam 10 in. wide by 18 in. deep will weigh 180 lbs. per lineal foot. Inclined slabs, such as often occur in power-house floors and saw-tooth roofs, will cause an overturning movement to the top of the posts, and this must be taken care of by adequate bracing.

The assumed construction live load is generally taken as 75 lbs. per sq. ft. of floor. This value should always be used in designing floor sheathing and joists ; but when calculating the deflection of joists it can be reduced to 40 lbs. per sq. ft., as it will only exist during concreting and then only for short periods. After a bay is concreted there will only be the dead load to be carried, and 40 lbs. per sq. ft. will allow for any accidental loading. Live load on ledgers is often omitted when calculating deflection.

For the good of both the concrete and the forms, the piling of timber, steel, cement, etc., on freshly-poured concrete should not be allowed. If it is known beforehand that, owing to confined space, some material must be placed on the concrete the day after it is poured, then the forms should be made extra stiff and should be designed to carry this loading with a small deflection.

Pressures.—In vertical sections, such as columns and walls, a horizontal pressure will act on the forms due to the hydrostatic head of the wet concrete. This pressure may be the cause of bulges and collapse of forms. It is a much debated point what pressures should be allowed for in the form design, and it is a subject about which there is as yet not much definite information. The pressure will depend on the rate of filling and the temperature. The faster the forms are filled, and also the lower the temperature, the greater will be the pressure, because the concrete does not set so quickly and thus relieve the pressure. If a wall were poured so slowly that each layer set before the next layer were poured, when the wall was full the pressure at the bottom would be no greater than at the top. This is the principle of moving forms with which elevators and bins of all kinds and sometimes walls are built. The form is raised at about the same rate as the concrete sets, so that each layer supports the layer above.

Fig. 86.—Reinforced Concrete Factory Building at New Malden.

Concrete at a low temperature will set slowly, and for a given rate of pouring the pressure may be 50 to 75 per cent. greater than when the temperature is twice as high. For this reason forms should be built stronger in very cold weather than in the summer, and not stripped so soon. Temperature considerations are, however, not often taken into account in designing forms, except in very cold weather, and the pressure is based on an average temperature allowing an ample factor of safety.

Rate of pouring is more important, and must be taken into account. Wall and column failures have occurred by pouring concrete too fast, or, if it was necessary to pour fast, by designing the forms too weak. Vertical sections should always be poured as slowly as is consistent with economy, and in long layers about 12 in. thick. Concrete in heavy walls and piers, in which large stones or "plums" can be embedded, will always exert less pressure on the forms than when the stones are omitted, because true hydrostatic pressure will not exist.

Fig. 87.—Leas Cliff Hall, Folkestone: Reinforced Concrete Frame Building.

Since the outward pressure depends mainly on the rate of pouring, column sides will be under greater pressure than wall sides, since they are filled faster. Column forms, however, should never be filled to the top without a break; instead, each batch of concrete should be distributed amongst several columns. For column forms a hydrostatic pressure equivalent to that due to a liquid weighing 125 lbs. per cu. ft. should be used; that is, the pressure on any yoke per lineal foot will be the depth from the top multiplied by 125 multiplied by the spacing apart of the yokes.

Small low walls may be poured as fast as columns and the same pressure should be used, but the higher and wider the wall the slower will it be filled and the pressure exerted at any point will correspondingly decrease. With ordinary thicknesses of walls it is simpler, for calculation purposes, to consider the height of the wall instead of the rate of pouring, the one being proportional to the other. The width does not affect the pressure, but does influence the speed of pouring, so that thin walls should be poured more slowly than thick walls, assuming that they are not designed for fast pouring. To some extent in narrow walls friction and arch action reduce the hydrostatic pressure. The following is a useful guide to follow in designing ordinary walls in order to be on the safe side.

Height of Wall.	Pressure will be equivalent to that of liquid weighing
Less than 5 ft.	145 lbs. per cu. ft.
,, ,, 5 ft. to 10 ft.	125 ,, ,, ,,
,, ,, 10 ft. to 20 ft.	100 ,, ,, ,,
Over 20 ft.	75 ,, ,, ,,

Fig. 88.—The New Kelvin Hall, Glasgow: Reinforced Concrete Frame Faced with Brick and Stone.

The consistency of the concrete also affects the pressure, increasing with the increase of the percentage of water in the mix.

As formwork is only temporary, higher unit stresses may be allowed than would be permissible in permanent work. For yellow pine, spruce, fir, and timbers of equal strength a maximum fibre stress of 1,200 to 1,400 lbs. per sq. in. for bending may be used, the former value being most common and is conservative. For horizontal shear 200 lbs. per sq. in. should be used, and for bearing or crushing across the grain 400 lbs. per sq. in. For American long leaf or pitch pine these stresses may safely be increased by 50 per cent.

For posts with square end bearing the maximum allowable compressive stress should be 1,000 lbs. per sq. in., to be reduced according to the ratio of the height or unsupported length to the least diameter by the formula

$$\text{safe unit stress} = 1{,}000\ (1 - h/80d),$$

where h is the unsupported length and d the least dimension of the cross-section. For ordinary conditions this gives a unit stress of about 750 to 800 lbs. per sq. in., which is twice that allowable for compression across the grain. Therefore the size of posts will generally be limited by compression across the grain in the timbers they carry.

If oak or other hardwood caps or wedges are inserted between the load-carrying member and the top of the cap, the allowable unit compressive stress across the grain may be increased 50 per cent.

Fig. 89.—Reinforced Concrete Factory at Hayes.

For the purpose of calculating deflections the modulus of elasticity may be assumed at 1,200,000 lbs. per sq. in., which is the value commonly used for pine.

In addition to strength in bending and shear, form members must be designed so that a safe maximum deflection will not be exceeded. This may be taken at $\frac{1}{8}$ in. for sheathing, using the full live load of 75 lbs. per sq. ft. For joists and beams carrying joists the deflection should not exceed $\frac{1}{8}$ in. for dead load and a live load of 40 lbs. per sq. ft. For members under horizontal pressure, deflection should not exceed $\frac{1}{8}$ in. Deflection considerations will generally govern the thickness of sheathing.

Timber Sizes.—It must be noted that the actual dimensions of dressed wood will be less than the nominal by an amount varying from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. This must be allowed for in design, as it makes a considerable difference to the strength of a timber, especially in the small sizes. If the dressed sizes are not specified when ordering the following allowances should be deducted :

For sheathing up to 2 in. in thickness, deduct $\frac{3}{16}$ in. from the nominal thickness; for timbers 2 in. by 4 in. up to 6 in. by 6 in., deduct $\frac{1}{4}$ in. from each dimension ; for timbers larger than 6 in. by 6 in., deduct $\frac{1}{2}$ in. from each dimension.

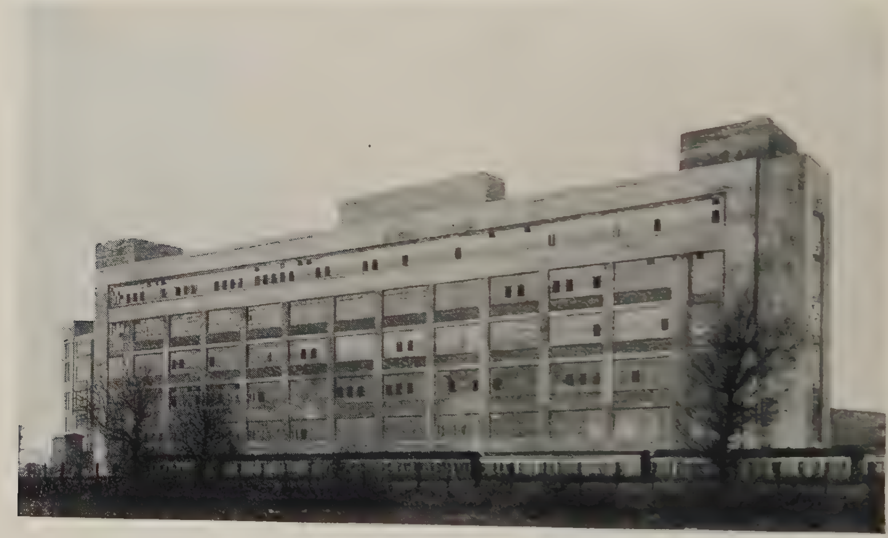


Fig. 90.—Reinforced Concrete Factory at Hayes.

Before placing any concrete the steel should be inspected and the forms examined to see that there are no shavings, dirt, or even small tools lying in them.

These notes on formwork are from "Design and Construction of Formwork for Concrete Structures," by A. E. Wynn, B.Sc., A.M.Am.Soc.C.E., which gives complete tables and designs for formwork for every type of structure.

Steel Forms.—In wall, tank and column construction steel forms are often more economical than timber, especially on large jobs where the forms are repeatedly reused. Steel forms require less expenditure per square yard on erection and stripping and their use results in smoother surfaces on the finished structure. Some contractors use their own design of steel forms, but the more general practice is either to hire or buy outright a quantity of the patented forms which are now on the market.

The general principle in steel form design is to use panels varying from about 24 in. square to 48 in. by 24 in. with narrower widths for filling-in, stiffened at the edges with angle-iron and fastened together by clamps, clips, wire, spikes, etc. Metal forms are also available for curved work. Two of these systems are shown in *Figs.* 92 and 93. Where more than two courses of panels are used in wall-work adjustable steel aligners are fastened to the forms. These make the formwork more rigid and help in the alignment of the panels. The plates are all interchangeable. Special plates with an adjustable closing device are supplied to complete the circumference of circular tanks.

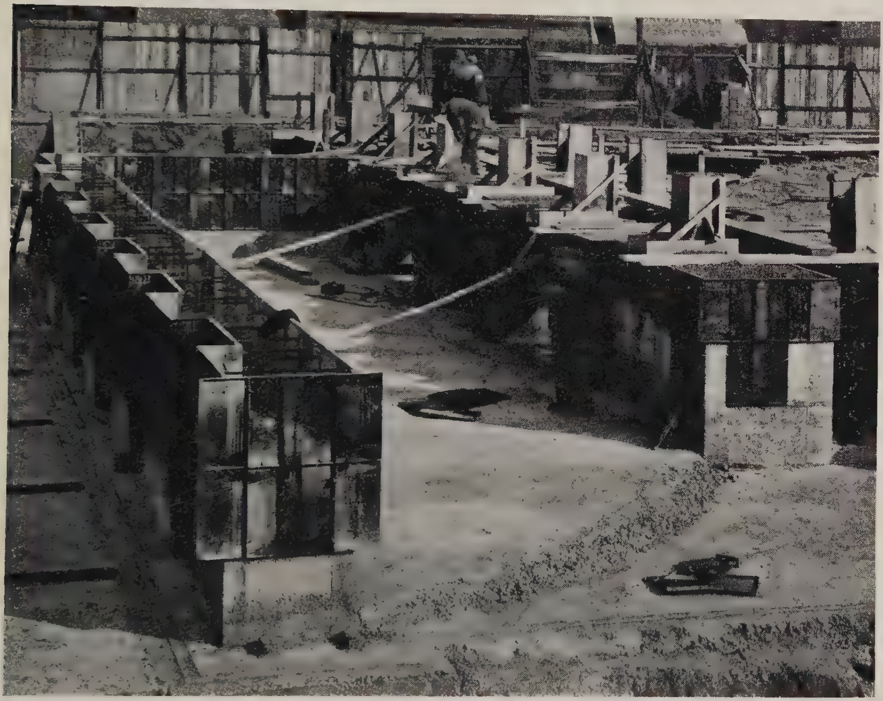


Fig. 91.—Steel Forms in Use at Greenwich Baths.

Another system (*Fig.* 91) comprises adjustable stanchion plates, wall or floor plates, closer plates and beam plates. The plain plates are stiffened around the edges and all the flanges are interchangeably holed. Stanchion plates are made either 48 in. by 21 in. or 48 in. by 16 in., the former

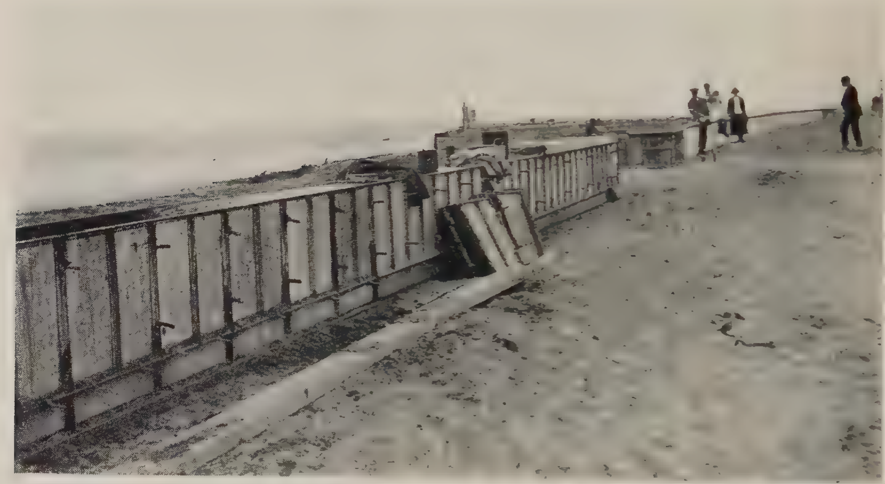


Fig. 92.

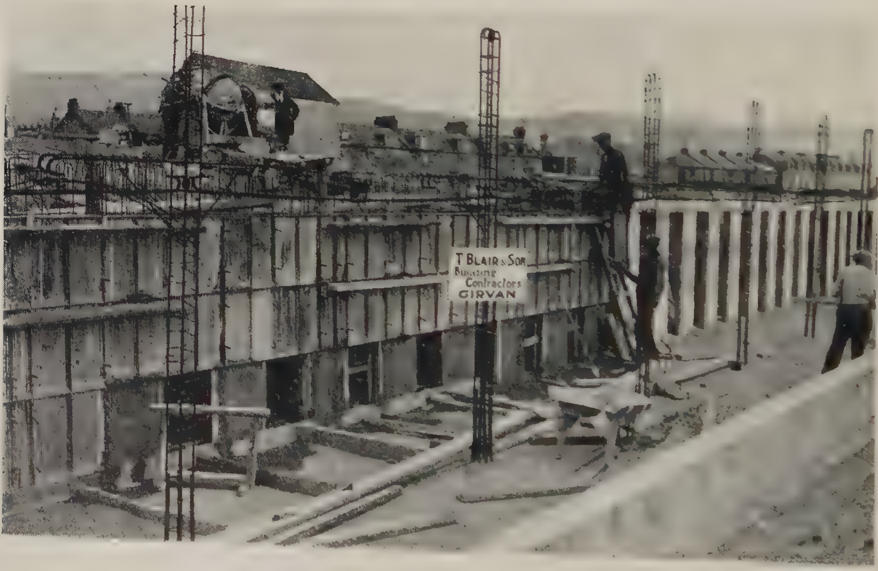

T BLAIR & SON
Building
Contractors
GIRVAN

Fig. 93.

being adjustable in width from 20 in. to 12 in. and the latter from 14 in. to 7 in.

Moving and Sliding Forms.—In the erection of circular silos, water tanks, surge tanks, etc., the forms may either be constructed as fixed,

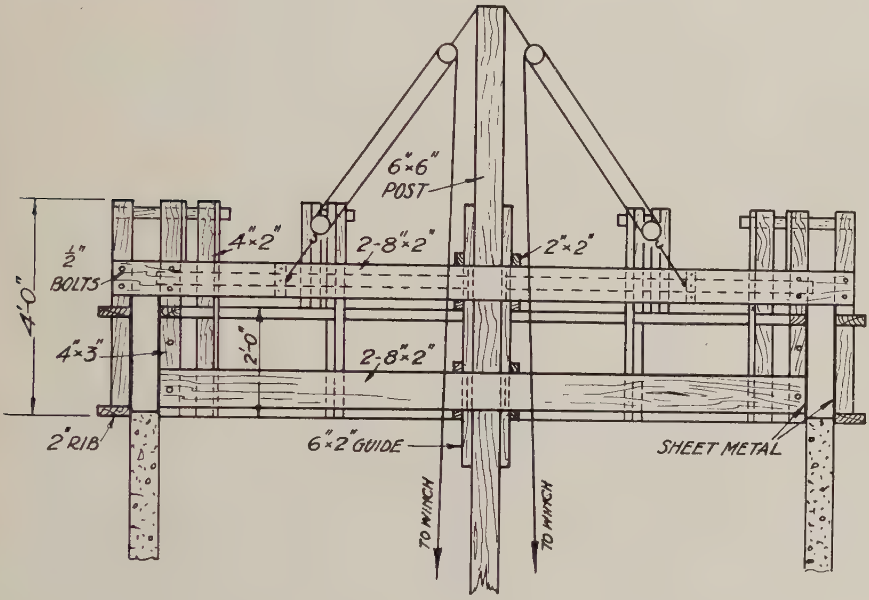

6"×6"
POST
4"×2"
2-8"×2"
2"×2"
½"
BOLTS
4'-0"
4"×3"
2'-0"
2-8"×2"
2" RIB
6"×2" GUIDE
SHEET METAL
TO WINCH
TO WINCH

Fig. 94.—Section.

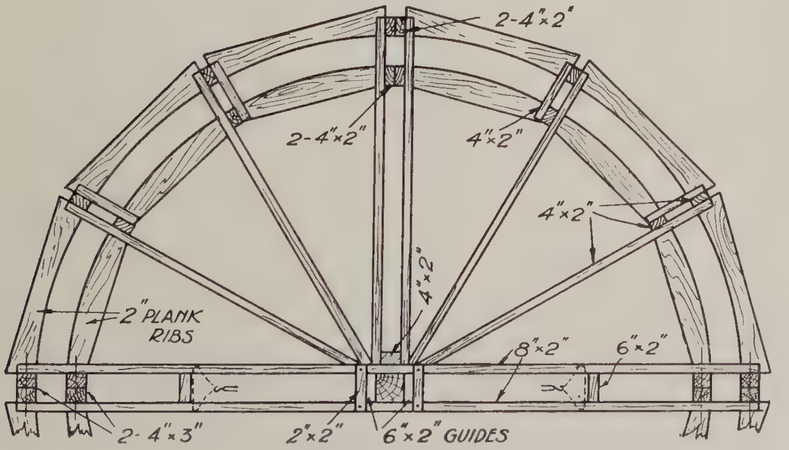

2-4"×2"
2-4"×2"
4"×2"
4"×2"
4"×2"
2" PLANK
RIBS
8"×2"
6"×2"
2-4"×3"
2"×2"
6"×2" GUIDES

Fig. 95.—Plan.

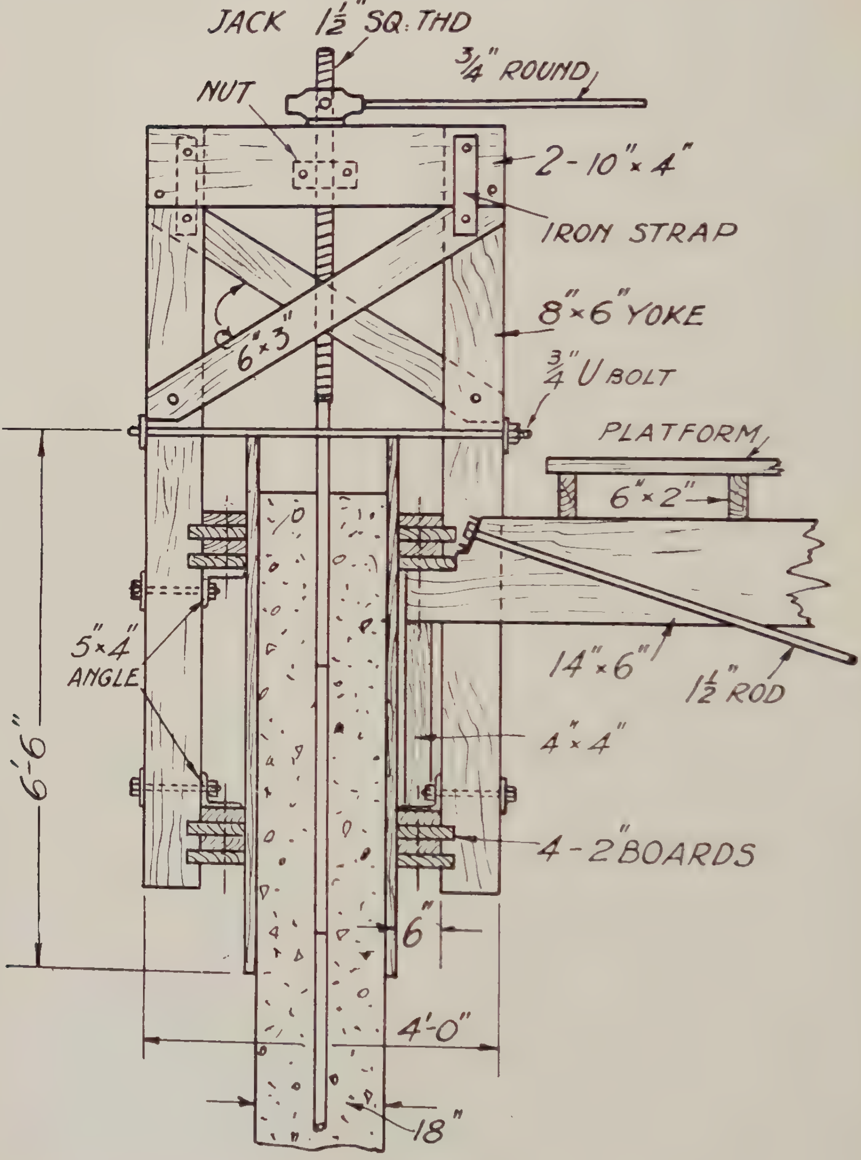

JACK 1½" SQ: THD
3/4" ROUND
NUT
2-10" × 4"
IRON STRAP
8" × 6" YOKE
6" × 3"
3/4" U BOLT
PLATFORM
6" × 2"
5" × 4" ANGLE
14" × 6"
1½" ROD
4" × 4"
4-2" BOARDS
6'-6"
6"
4'-0"
18"

Fig. 96.—Section.

moving or sliding. The first type is only economical for low walls and diameters of less than 30 ft. The second is suitable for silos in which the presence of construction joints is not harmful and where the total amount of concrete to be poured is small. Continuous sliding forms are employed where the structure must be monolithic and where the form can be kept moving upwards at a uniform rate while the concrete is being placed.

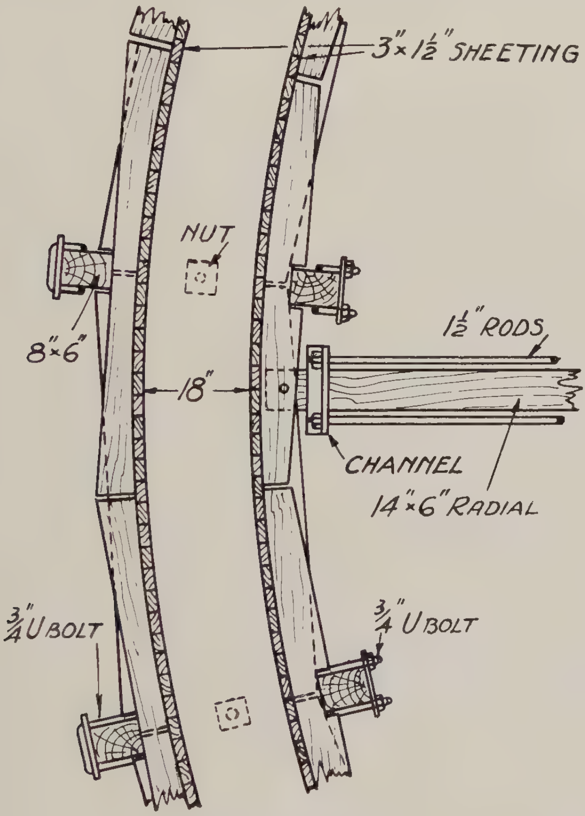


Fig. 97.—Plan.

An example of moving forms is illustrated by *Figs.* 94 and 95 in which it will be observed that the form is lifted on a central post. Larger moving forms must be raised in sections on several posts. In the illustration both inner and outer wall forms are built in four sections each of which is constructed of 2-in. ribs with 4-in. by 2-in. uprights about 4 ft. long between each pair of ribs, and a 4-in. by 3-in. upright at one end of the section. Each section is covered with sheet metal. In erecting the forms the outside sections are bolted together first with ½-in. bolts. A pair of 8-in. by 2-in. timbers is then bolted to the outer uprights, just above the top of the section and a similar pair to the lower ends of the inner uprights. Between these 8-in. by 2-in. timbers runs the 6-in. by 6-in. post on which the form moves, the movement being kept vertical by means of 6-in. by 2-in. timbers nailed to the 8-in. by 2-in. to form guides.

Intermediate stiffeners of 4-in. by 2-in. timber are run from the top and bottom of each upright to the centre. The form is raised by winches with ratchets to hold it in position.

Sliding forms are constructed with built-up ribs continuously bolted together and suspended from yokes at 5 ft. to 6 ft. apart (*Figs.* 96 and 97). The yokes consist of pairs of 8-in. by 6-in. verticals passing through notches in the ribs and connected to them by steel angle irons. The yokes extend to 3 ft. 6 in. above the sheeting. At the level of the top of the sheeting the yokes are held together by **U**-bolts. The top sill is bolted to the verticals and carries the square-threaded nut.

The jack shown in *Fig.* 96 consists of an upper threaded portion 1½ in. diameter and 4 ft. long with three square threads to the inch, and a lower shank ⅞ in. diameter and 3 ft. 6 in. long, all in one piece. For the full length of the threaded portion a square slot is cut in the circumference. The turning head is a casting with four arms bored to take a ¾-in. bar and with a 1½-in. diameter hole in the centre so that it will slip over the jack. There is a square projection in the side of the hole that will fit the slot in the jack. The head is therefore free to slide up and down, but cannot turn sideways without turning the jack. This arm always rests on the iron plate across the headpiece. The shank of the jack is inserted in a plain piece of 1-in. pipe 3 ft. long, and the pressure of the jack is transmitted by the collar at the junction of the threaded portion and the shank. As the headpiece is turned with a bar, the jack working within the nut attached to the yoke and pressing on the pipe will raise the form.

PLACING AND RAMMING CONCRETE

The plant required for transporting the concrete from the mixer to the forms will vary according to the magnitude of the job and the height above ground-level at which the concrete is to be poured. Obviously very expensive plant, however quick in operation, cannot be economically used to pour small quantities of concrete since the cost of erection and dismantling of the plant and the plant charges while it is out of use would be spread over only a small number of cubic yards and the plant charges per cu. yd. would be excessive.

For transport of concrete from the mixer, barrows, concrete carts or jubilee skips are most commonly used in placing concrete at ground level or in work below ground where some type of wheeling is necessary. *Fig.* 57

shows a special concrete hand-cart, while in *Fig.* 66 is shown a hand-cart with separate divisions for cement, sand, and gravel, each division being the correct size to hold the correct proportions of each material included in a batch. *Fig.* 59 shows jubilee skips as used for transporting concrete. If barrows are selected they should be deep so that concrete is not spilled while they are being wheeled. Since the capacity of a barrow is only about 2 cu. ft. it is preferable to employ concrete carts which have a nominal capacity of 6 cu. ft. and can be handled by one man if a runway is laid down. If, however, the wheeling is to take place over a runway supported on scaffolding the latter must be practically the same for barrows as for carts and in this case the carts need not be debited with extra charges for scaffolds.

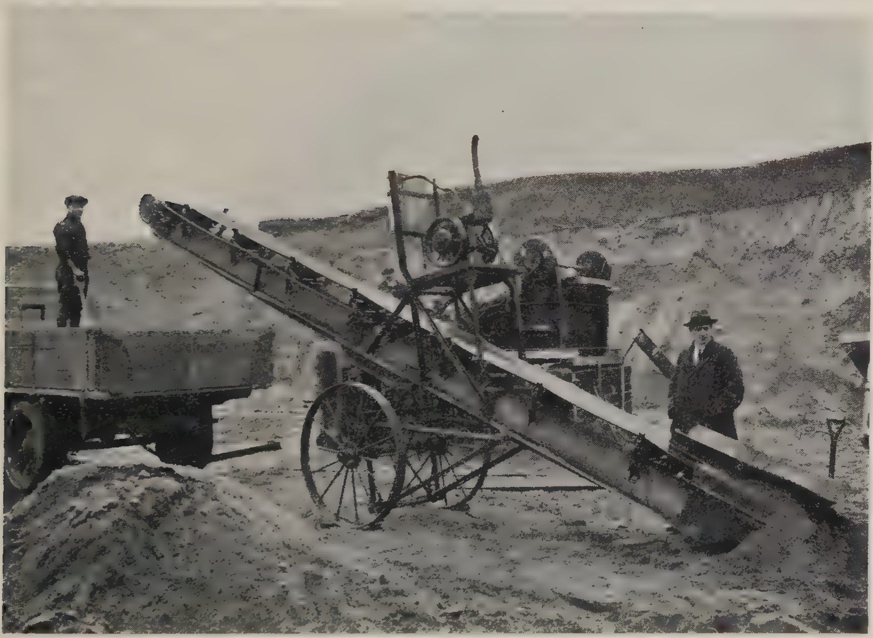


Fig. 98.

Jubilee skips, laid on light steel rails and sleepers and provided with turntables, are useful for work at ground level when the track has not to be moved often.

In some cases such as basement slabs transport costs can be almost eliminated, by discharging the concrete from the mixer directly into wood or steel chutes leading to the form. Belt conveyors (*Fig.* 98) are also used in a similar fashion to raise concrete from the mixer level to wall forms which stand above the ground. Conveyors, however, are limited to a slope of about 30 degrees and, of course, entail extra plant charges. By employing a locomotive crane with a dumping or tilting bucket, running between the mixer and the place where the concrete is required, the latter may be poured economically if in large quantities.

In building work some form of hoist or chuting plant is essential to lift the concrete from ground-level, either to a hopper from which it may be discharged into barrows, etc., and wheeled away or to a distributing plant with sheet-metal chutes. The latter is an ideal method if the building is approximately square in plan, but the height of the tower must be sufficient to ensure that the slope of the chutes is not too flat or there will be difficulty in getting the concrete to flow properly unless it is extremely wet.

In erecting a chuting plant the mixer is placed so that it can discharge direct into the hoist bucket, which is raised by the hoisting engine. The guides for the hoist are so arranged that the bucket is automatically tilted at the desired level into a receiving hopper-head for distribution. Both timber and steel towers are used successfully in this class of work. The chutes are constructed of steel plate stiffened by angle irons and are about 9 in. deep and 9 in. wide at the top. So far as possible no rivets or bolts should pass through the bottom of the trough, or the free flow of the concrete will be prevented.

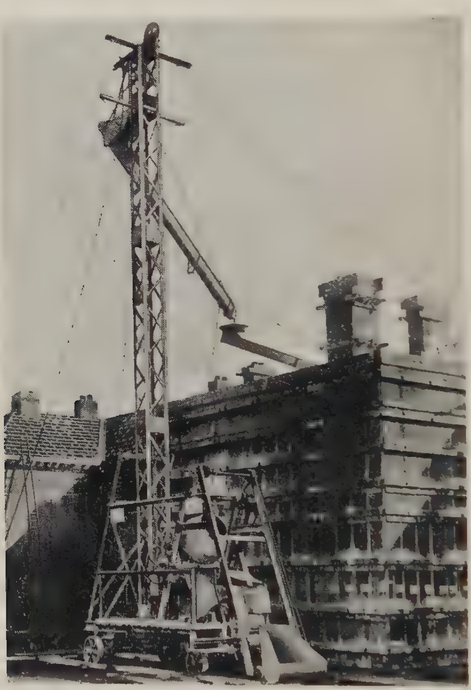


Fig. 99.

Although the concrete is rammed after delivery to the forms it is absolutely necessary to prevent segregation in the chutes. A chuting plant is shown in operation in *Fig.* 99.

Fig. 100 shows a hoist used for elevating concrete in carts to the upper floors of a building ; this saves re-handling, as the concrete is tipped into the cart from the mixer and is not handled again until it is poured into the forms.

The methods to be adopted in tamping or ramming the concrete in the forms vary with its consistency. Where a dry mix is specified for mass concrete work the layers of concrete should be rammed using a tool at least 6 in. square as each 12 in. thickness is placed in position. With reinforced concrete for thin sections a wetter mix is desirable in order to avoid honeycombing and with such mixes lifts of 3 ft. are common practice. Commonly used types of tampers for such work are (*a*) a piece of 3-in. by 2-in. timber shaped so that the upper portion forms a handle, (*b*) a similar tool but fitted with a steel shoe, (*c*) an ordinary spade, (*d*) a $\frac{3}{4}$-in. steel bar with a short right-angle bend at one end, and (*e*) special manganese steel rammers with holes in the face.

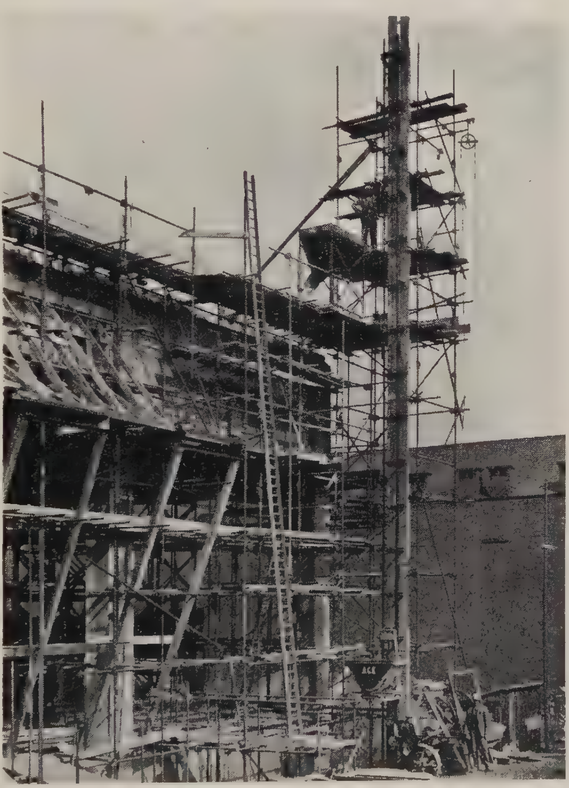


Fig. 100.

When it is necessary to join new concrete to concrete which has already hardened, the surface of the latter must be cleaned so as to be free from all foreign matter and the laitance must be removed. If the surface is smooth it must be roughened and soaked with water. The use of dilute hydrochloric acid is sometimes allowed for the purpose, but great care must be taken to remove all traces of acid before concreting starts again. "Retardo" (see page 102) is also recommended for this purpose. Before placing the new concrete the old surface should be painted with a neat cement grout to a depth of about $\frac{1}{16}$ in.

In order to prevent excessive shrinkage cracks all freshly-placed concrete should be cured under water or kept damp in some manner and protected from the direct rays of the sun. Wet canvas, shavings, or sand are some of the materials used for this purpose. The use of shavings is not to be recommended as they may have a deleterious effect on the concrete.

Concreting Below Water-Level.—In certain classes of work it is necessary to pour concrete below water-level. If the concrete were simply shot down into the water a large proportion of the cement would be washed away; to avoid this a tremie is used (*Fig.* 101). This usually consists of a steel pipe, with a hopper-head into which the concrete is filled, and a gate-valve at the bottom. The valve is first closed, the bottom of the tremie being just clear of the level at which the concrete is to be poured, and the pipe filled nearly to the top. The valve is then opened gradually by a lever worked from above water-level and the concrete allowed to escape. The essential precautions are to fill the pipe at the top end as quickly as it is emptied below and to raise the lower end as the level of the poured concrete rises.

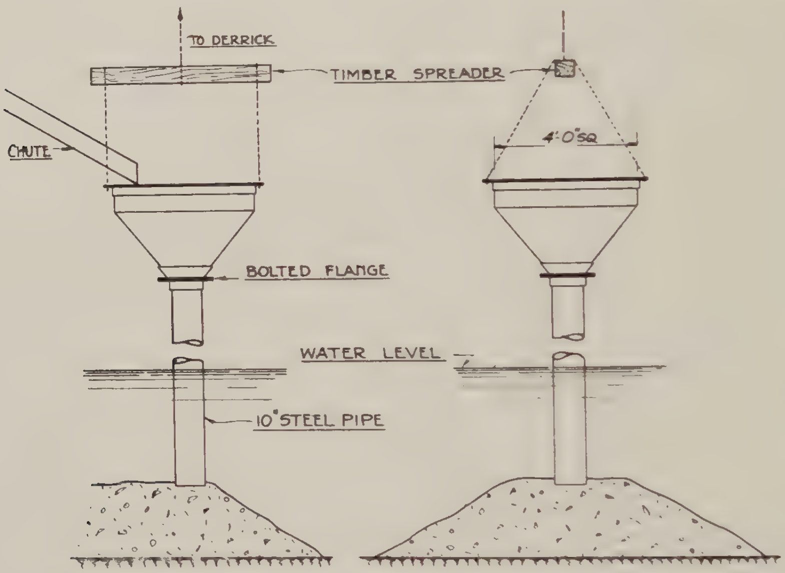


Fig. 101.

Other methods are to fill the mixed concrete into jute or paper bags and lower these to the bottom where they are set as headers and stretchers by a diver. Iron dowels driven through two adjacent bags are useful in preventing the bags from shifting under wave-action, which goes on to some considerable depth below the surface. In some types of breakwater and quay construction very large pre-cast concrete blocks have been placed below low-water by means of sheer-legs or a traverser crane mounted on a pair of barges with a space between them through which the blocks could be lowered when the barges were anchored over the site of the wall.

CONCRETING IN HOT CLIMATES

In order to ensure successful results when concreting is being carried on in hot climates precautions must be taken so that the freshly placed concrete is properly cured. During the period in which setting and hardening are taking place the concrete must not remain uncovered or exposed to the direct rays of the sun. In tropical climates the evaporation is so intense that there is always a risk of the water required for the chemical actions being removed before these have taken place. To overcome this danger and prevent the occurrence of shrinkage cracks the fresh concrete is usually covered with canvas, which is kept saturated with water. If at all possible the concrete surface should be flooded with water, and in any case the forms should be soaked with water before commencing to pour the concrete. The use of sawdust or straw as a covering cannot be recommended as there is a danger that these materials may contain chemicals which will either stain or injure the concrete. Strips of hessian are useful for covering vertical work, and these should be kept wet.

Concrete in large areas, such as floors, may be covered with sand which is kept wet or be cured by ponding, a process in which a low dam of clay is built round the concrete to retain the water used to form the pond. Small pre-cast concrete articles may be steam cured.

PART III

SURFACE TREATMENT

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SURFACE TREATMENT

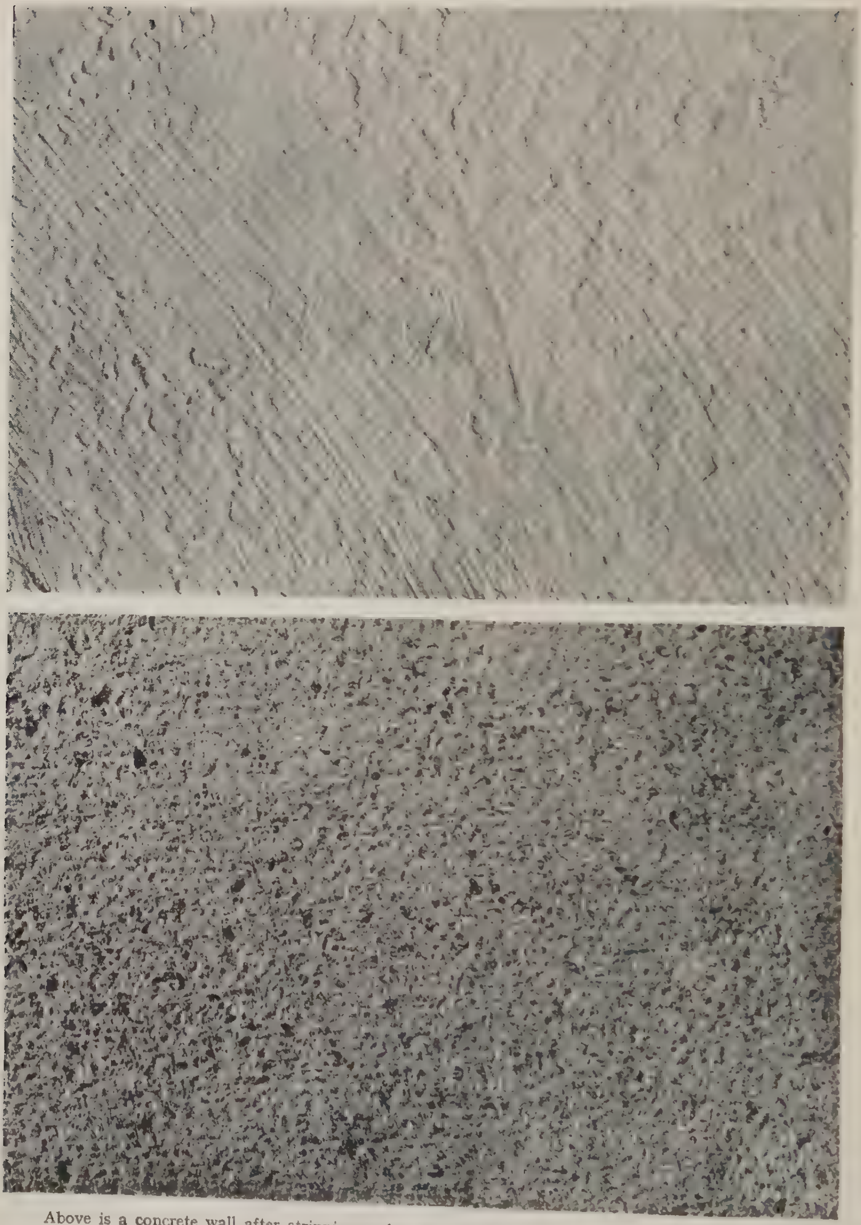
SINCE an interest has been taken in the appearance of concrete great strides have been made in developing methods of producing concrete surfaces that are pleasant to the eye, and which obviate any necessity for covering concrete with another material, as is so often done for æsthetic reasons. A realisation of the fact that it is not sound economics to cover the most weather-resisting of all building materials with a material which more readily disintegrates with exposure has led architects and engineers to take a real interest in the various methods by which this waste of materials can be avoided. The methods range from the simple process of cleaning down concrete surfaces to give a presentable appearance to buildings of the factory and warehouse type to the production of finishes that cannot be distinguished from natural stone, and which appeal to the architect because of their superior weathering properties and lower cost. All the processes in use are described and illustrated in the following notes.

Ordinary Concrete Finish

Buildings of the industrial type are usually simply cleaned down to remove the inequalities and marks left from the shuttering, and given a wash of cement. Bolt and other holes should be filled, and any fins left between the joints in the formwork, and other excessive roughnesses, rubbed down. It will generally be found cheaper to pound off projections with a flat-headed hammer than to cut them away with a chisel. Concrete wall surfaces before and after cleaning down and tooling are shown in *Figs.* 102 and 103.

Cement washes of practically any colour can be prepared by using coloured cement and sand. Coloured washes are also dealt with on p. 106; the following notes apply to both ordinary grey and coloured cement washes.

After the cement and sand in the desired proportions are thoroughly mixed in the dry state, the mixture should be added slowly to water, stirring vigorously until the consistency is that of a stiff oil paint. The dry batch should be large enough for a full day's work, but only enough of the wash should be prepared to last one hour. The wash should be thoroughly stirred in the container before each application to the concrete surface, and when refilling the container all the old wash should be cleaned out and discarded. The area to be coated should first be thoroughly wetted, and then a full



Above is a concrete wall after stripping and patching. Below is the same wall after tooling.

Figs. 102 and 103.—Concrete Wall Face before and after Surface Treatment.

brush coat of the wash applied. This coat should be rubbed in with a cork float, the surface being sprinkled with a little additional water if necessary. Finally the surface should be gone over with a clean damp brush, brushing in the direction of the board marks.

In this process all excess material should be removed, and the remaining coat should be as thin as will permit the surface to be entirely covered. In warm or drying weather the finished surface should be sprinkled with water 2 or 3 times a day for 3 days, and in cool, damp weather should be sprinkled at least once within 24 hours after finishing. Sprinkling of the freshly-coated surface is necessary, for if the wash dries before it has attained its set it may dust off. The sprinkling must be gentle so as not to wash off the fresh coating. The sand must be dry before screening, not only to facilitate the screening but also to avoid the possibility of moisture in the sand causing a set in the dry mix.

A better appearance is obtained if the wash is rubbed in with a carborundum stone. This not only ensures a better bond by more positively forcing the material into the pores of the concrete, but at the same time grinds down any slight projection, leaving a semi-rubbed surface.

An effective method of ensuring the bond of the wash coat is to use a 4 per cent. solution of commercial calcium chloride as the gauging liquid instead of plain water. This solution is made up by dissolving 1 lb. of the chloride in 3 gallons of water. The calcium chloride attracts moisture from the air and keeps the wash coat damp for several days, thus ensuring that the cement sets before it dries out.

Rubbed Finishes

Rubbed finishes are obtained with carborundum stones. The first rub should be completed as soon as the forms can be removed; it will be realised that the longer the rubbing is delayed the more difficult, and consequently more expensive the process will be.

If a hard aggregate is used, such as granite, rubbing cannot be effective at 24 hours since the cement will not be hard enough to hold the aggregate and the latter will be torn out. As soon as the forms are removed the surface should be thoroughly wetted and then rubbed with No. 20 carborundum stone. The rubbing will remove board marks, nail-head marks, and to a certain extent the irregularities between boards.

The cement paste which works up in the rubbing process should be removed by washing and brushing. Small voids in the concrete should be filled with a mortar (usually 1 : 2) composed of finely-screened aggregate of the same general description as that used in the concrete. This mortar should be worked into the face with the carborundum stone and left even and regular.

The most economical results are obtained by applying the first rub to the concrete while it is green. Filling the small voids with mortar offers no difficulties, but the operator should be warned against leaving an appreciable thickness of mortar on the face of the concrete to take up irregularities in the surface, unless special precautions are taken to ensure the bond. Such precautions are particularly necessary when the surfacing is delayed until the concrete has hardened and dried out.

If the concrete cannot be given the first rub when it is still green, board marks, nailhead marks, and small projections must first be removed. After thoroughly wetting, the surface should be coated with a cement wash in order to help the grinding action. The carborundum rub should then be given, taking care to remove all the cement wash by washing and brushing.

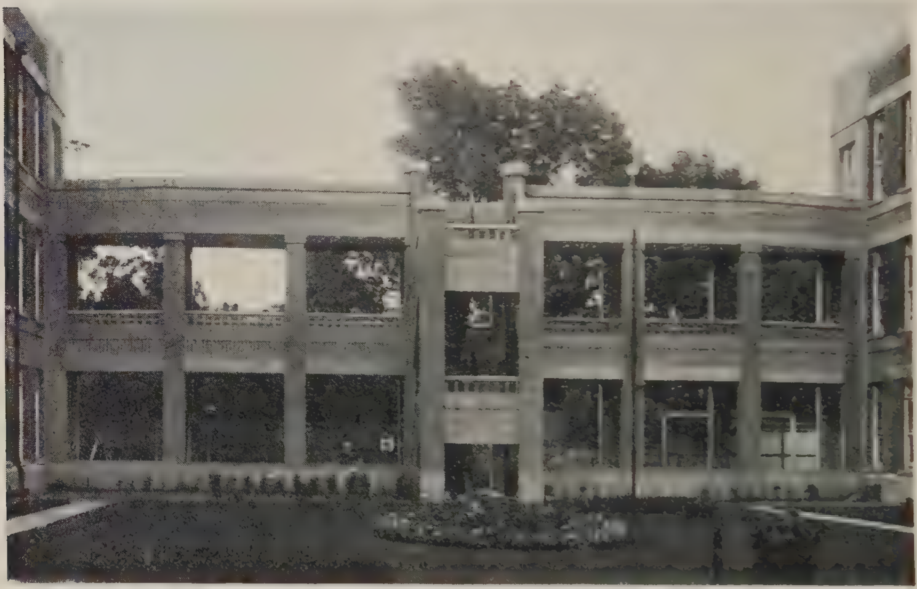


Fig. 104.—Extensions to Lewisham General Hospital, showing Special Exposed Aggregate Surfaces.

The second rub should be applied near the end of the work, when the building is ready to be cleaned down and danger of staining from other work is past. The surface should be thoroughly wetted, and then gone over with a No. 24 carborundum stone. The paste which is worked up should be removed with a wet brush.

Exposed Aggregate

This treatment is perhaps a natural outcome of the desire on the part of the architect to express on the surface of a building the materials of which it is made. Concrete as it leaves the forms has a film of cement on the surface, and, so far as the eye can ascertain, the structure is built of cement alone. But the cement content is perhaps only one-fifth or one-sixth of the materials of which the concrete is made, and a more true impression of the material is gained if the nature of all the constituent parts is shown on the surface.

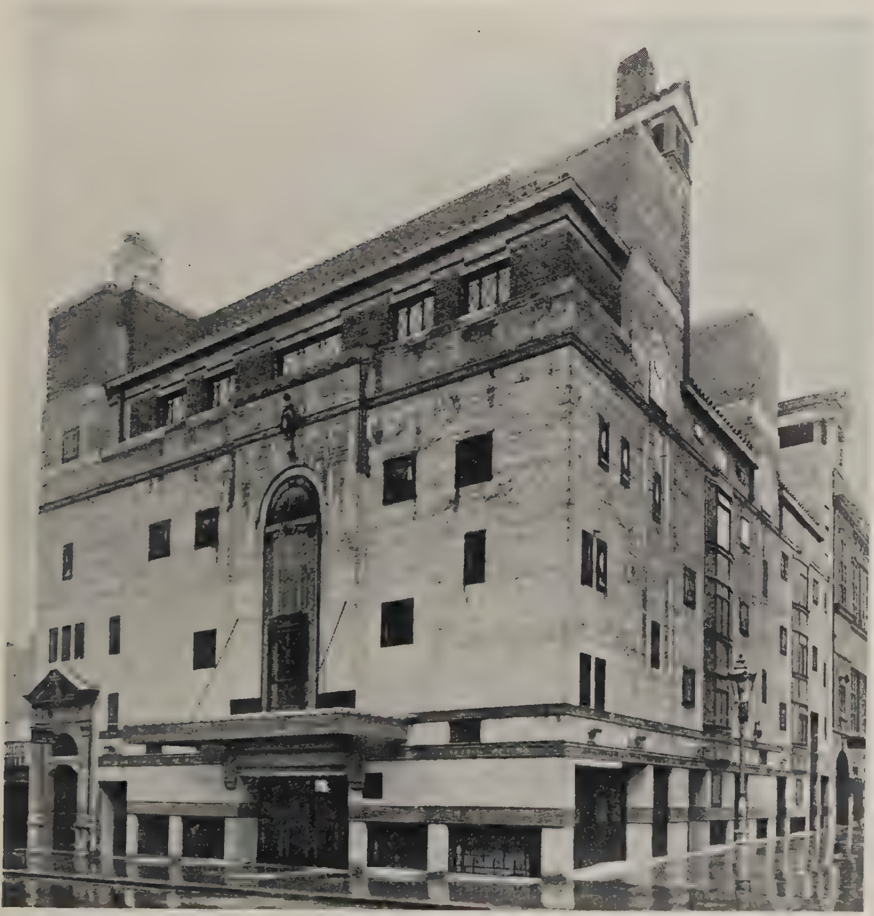


Fig. 105.—The "Fortune" Theatre, London: A Surface-treated Concrete Façade.

The idea of the exposed-aggregate surface, then, is to obtain on the surface a texture similar to that which would be seen if the film of cement were removed from the concrete, and the desired effect may be obtained in several ways.

The simplest method is to scrub off the cement film with a stiff brush and clean water, but this will only be effective if the scrubbing can be done before the cement has hardened. If applied too early after placing the concrete the brush will loosen the aggregate from the surface, and this is to be avoided. On the other hand, after the cement has hardened it is impossible to remove the cement by this means. No exact period can be laid down for carrying out the process, as the consistency of the mix, the curing conditions, and other factors affect the period which concrete requires to harden, but the scrubbing should be done as soon as possible after the concrete has been placed. By trying the effect of the brush on a small portion of concrete it can readily be ascertained whether it is hard enough to withstand hard scrubbing without disturbing the aggregate ; as soon as this can be done the work should be carried out, as if it is left too long the cement cannot be removed at all with water only.

This method is obviously only applicable to concrete that can be released from its mould, or from which the shuttering can be stripped, at an early age. Where this is not possible scrubbing with clean water is not sufficient, but a solution of muriatic acid will be effective. The solution should be no stronger than is necessary, and a mix of 1 part muriatic acid to 6 parts water should first be tried. If this is not effective the solution can be strengthened until the cement comes away with a reasonable effort.

When acid is used it is essential to remove all traces of it as soon as the aggregate is sufficiently exposed, as otherwise it will continue its action on the cement and loosen the surface aggregate. The concrete should therefore be thoroughly washed down with copious applications of clean water as soon as it has been treated. A liquid known as " Retardo " is now available for exposed aggregate treatment ; this is painted on the inside of the forms and has a retarding action on the set of the cement on the face of the concrete. Thus by using " Retardo " scrubbing the cement from the surface is simplified and cheapened.

Examples of scrubbed surface treatments are given in Plates I and II.

Tooled Finishes

This heading includes all finishes in which the surface of the concrete is mechanically roughened, or removed, to expose the aggregate. Wire brushes, stone-dressing tools, and rotary cutters are used for this purpose.

When coarse aggregate is to be exposed by wire brushing the concrete should be as green as possible, usually not over 48 hours old. Generally speaking, this process is not used on large buildings unless special effects are to be obtained, in which case the treatment, if it is to be successful, requires careful preparation and selection of aggregates, as well as care in concreting.

When bush-hammering (*Fig.* 106) or other tooling treatment is to be used, attention should be given to the layout of construction joints. The work should be planned to eliminate as many joints as possible, particularly horizontal lines. If the latter are unavoidable, care should be taken to level the concrete before leaving off work.

Where coarse aggregate is to be exposed by picking or hammering, it should be uniformly graded. The distribution of the aggregate should also be uniform for satisfactory results, and the consistency of the mix should therefore be carefully controlled in order to prevent the settling or segregation of aggregate.

When patching or filling of bolt holes is required on an area which is to receive a tooled finish, the tooling should precede the patching. The latter should then be done by a skilled workman, who should match the texture of the surrounding area by imbedding selected pieces of large aggregate in a mortar bed.

Surfaces to be finished with a rough texture should be at least two weeks old before finishing. The work may be executed by mechanical devices operated by air or electricity, or by hand-hammering. In general the work on any one panel or area should be done by the same operator in order to avoid differences in texture.

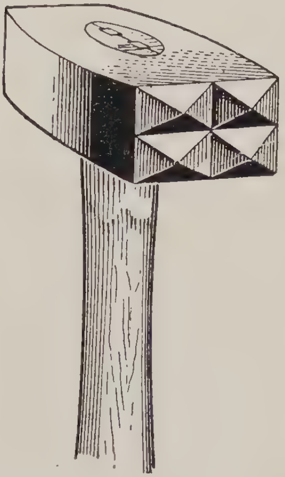


Fig. 106.—Bush Hammer.

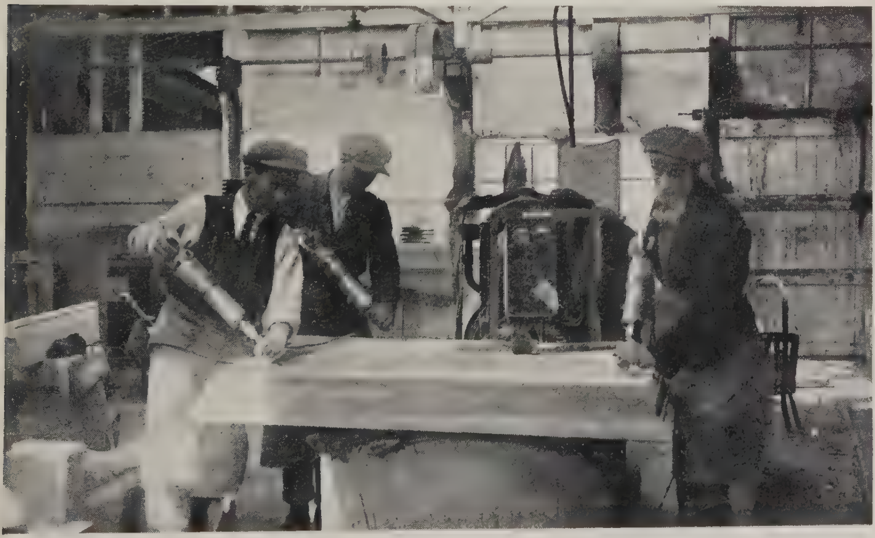


Fig. 107.—Power-driven Stone Chisels.

As tooled finishes are usually carried out in panel effects, care should be taken to lay out exact lines and to cut clean and sharp at the edges. The borders of the panels and such other parts of the surface as are not roughened must receive a washed or rubbed finish to balance with the tooled areas.

These methods of tooling apply to concrete in which ordinary ballast aggregate is used as well as to concrete made with selected natural stone and selected sand as the aggregate, the colour of the finished wall depending, of course, on the colour of the aggregate. If a special aggregate is used, economy may be effected by using it for the face only, using ballast concrete for the greater part of the thickness of the wall. In this method the centering for the concrete is constructed in the ordinary way, with the exception of that in contact with the face, which should be erected in not more than 2-ft. lifts and have temporary spacers to keep it 2 in. from the main reinforcement. Special care should be taken with the face timbering to ensure it being cleanly wrought and truly fixed. No. 16 gauge steel plates 2 ft. 6 in. long and about 3 ft. wide may then be placed edge to edge between the face shutter and the reinforcing steel, and lightly wedged up to the latter, leaving a continuous space of about 1½ in. between the plate and the shutter.

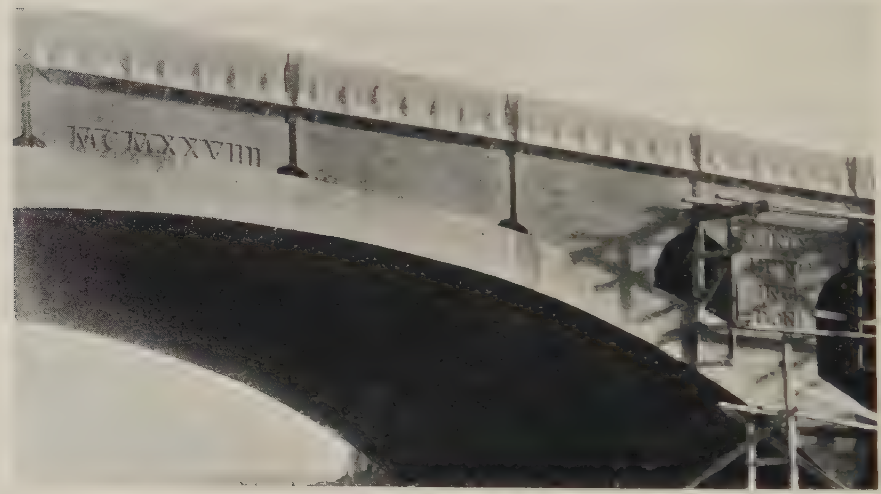


Fig. 108.—Wansford Bridge: Detail of Hammer-dressed Concrete Surface.

The special facing concrete is placed first and the ordinary structural concrete afterwards, keeping the latter always 6 in. below the level of the former. As the concretes are poured the steel plates are drawn vertically upwards, allowing the two wet mixtures to flow together but always keeping at least 3 in. of plate embedded in concrete to form a bottom fixing for subsequent lifts.

Success in obtaining a good face lies in the accurate grading and even mixing of the facing concrete, in placing the concrete in a fairly dry state so that the larger stones do not tend to sink to the bottom, in even tamping in small lifts, and in removing any scum which may rise to the top at the completion of each 2-ft. lift, or particularly at the end of each day's work. The first layer after a stop should be placed slightly wetter and very thoroughly tamped. The face centering should be removed as early as possible and the concrete finished with a wire brush to the desired texture. If any blemishes occur they should be filled immediately after the concrete is brushed with the screenings from the dry concrete according to the gauge required.

Special facing concrete is only necessary for buildings of considerable architectural importance, and ordinary concrete can be made to give an effect in every way suitable for industrial purposes. It is important to emphasise that the two layers of concrete remain such only during casting and that as soon as the temporary steel plate is removed they flow together and set as one mass without a mechanical joint.

Fig. 109 and Plates III and IV illustrate the results obtainable by tooling concrete in which crushed natural stone is used as aggregate.

There is now on the market a liquid known as "Retardo" which, when painted on the forms, prevents the cement from setting on the surface, so that the aggregate is exposed and no scrubbing or tooling is necessary.

Fig. 109.—Chiselled Concrete Surface.

When an exact representation of natural stone is desired the notes given in Part VII relating to cast stone should be followed.

Polished Surfaces

Polishing is done by rubbing the face of the stone with carborundum or hard stones. The carborundum is used to cut off the outer skin and to get the surface level. This is followed by rubbing with snakestone, hard York, or similar stone to produce the final polish. The degree of polish obtainable depends largely upon the nature of the aggregate, as some aggregates, such as marble chips, granite, etc., lend themselves more than others to this process. During the rubbing process, plenty of water must be used, and the scum occasionally washed off. Machines are obtainable for stone polishing, the most usual type consisting of carborundum blocks fixed in a rotating electric machine such as is shown in *Fig.* 111. An example of a polished concrete surface is shown in *Fig.* 110.

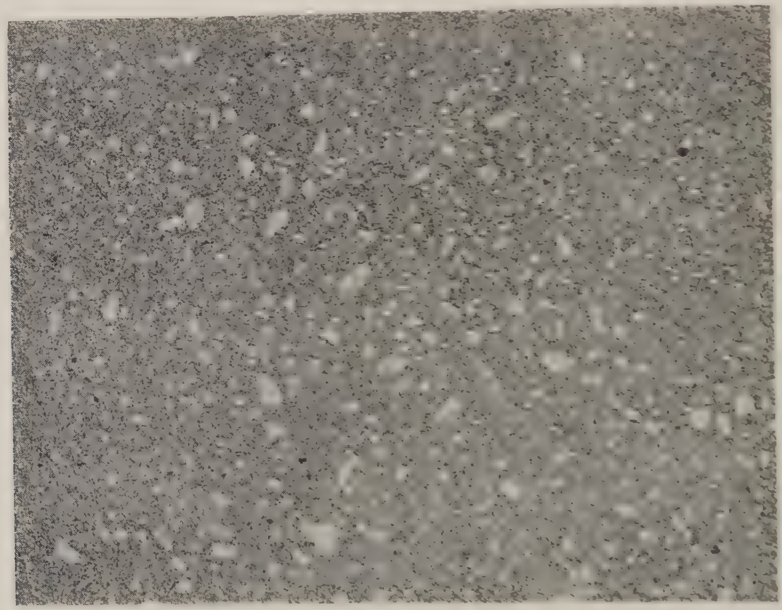


Fig. 110.—Polished Surface with Crushed Marble Aggregate.

Colouring

Coloured cement washes are made by the use of coloured Portland cement or by mixing pigments (usually metallic oxides) with Portland cement and water to form a thin mortar, or wash, and this is applied to the surface of the concrete in the same way as an ordinary limewash.

To obtain a white surface " Snowcrete " Portland cement should be used, and white Portland cement should also be used as a basis for any of the lighter shades of colour. Thus white Portland cement with yellow ochre or brown oxide of iron will produce cream, yellow, and buff shades. In any case it is best to make trial panels, which can be lightened or darkened as desired by varying the quantity of colouring material.

Colour Guide.—As different colours vary so much in shade, it would serve no useful purpose to give definite proportions of colouring materials to cement to produce given colours, but the following guide will be useful—varying shades may be obtained by trial and altering proportions until a satisfactory shade is produced :

Buff and Yellow—Yellow ochre or barium chromate.

Grey and Slate—Manganese black or lampblack. (Ordinary lampblack is unsatisfactory).

Brown—Burnt umber or brown oxide of iron.

Blue—Prussian blue or ultramarine.

Green—Green oxide of chromium or greenish-blue ultramarine. Green also results from a mixture of yellow ochre and ultramarine.

Pink or Red—Red oxide of iron, or crimson lake with alumina base.

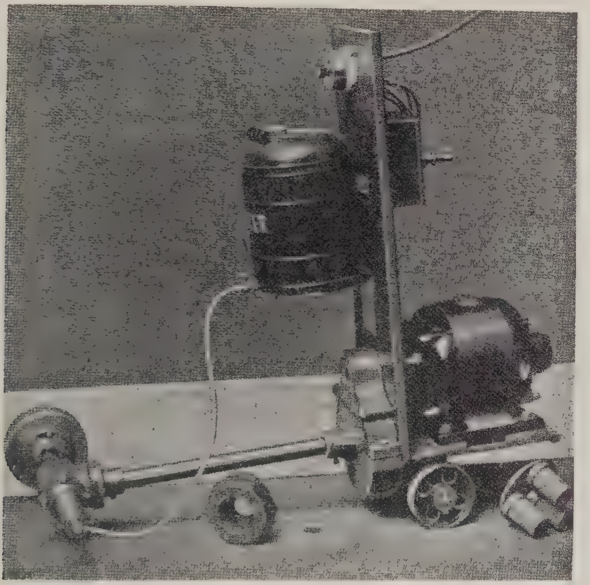


Fig. 111.—Surfacing Machine.

Chocolate—Manganese black, black oxide of iron or copper, and red oxide of iron, mixed together.

Black—Manganese black or lampblack.

By experiment it will be found that mixtures of these materials will produce any desired shade. For the darker shades ordinary grey Portland cement will give good results, but, as stated, white cement must be used for the lighter tints.

Mixing.—The cement and colouring material should first be thoroughly mixed dry, and then slowly added to water, stirring vigorously until it has the consistency of oil paint. Only sufficient of the wash should be mixed with water to last one hour, but it is preferable, for the sake of a uniform result, to mix sufficient in the dry state for the whole of the work. Two or more coats should be given if necessary.

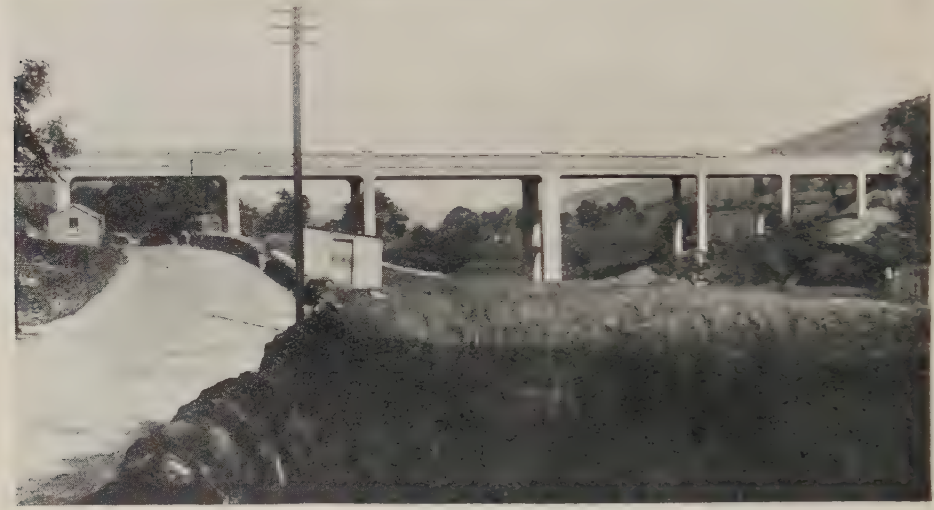


Fig. 112.—Reinforced Concrete Bridge in Derbyshire.

Precautions.—There are some precautions that must be strictly observed in the use of any pigment :

(1) The proportion of colouring material to Portland cement should

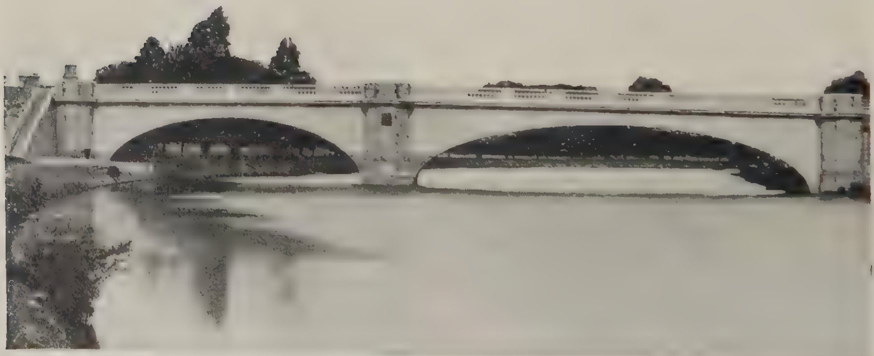


Fig. 113.—Royal Albert Bridge, Old Windsor: Reinforced Concrete Bridge over the Thames.

not exceed about 10 per cent. as larger proportions may weaken the concrete.

(2) Only mineral colours should be used as organic pigments are generally unstable and will fade when exposed to the sun, or they may be decomposed by chemical action.

(3) If the colour is applied as roughcast in which sand is used, the sand should be quite dry and clean. The use of wet sand is liable to cause the cement to set in the "dry" mix and a dirty sand will affect the colour.

(4) In very hot weather it is advisable lightly to spray the surface with water each day for three days after the wash is applied, as if the wash dries too quickly it is liable to rub or dust off.

Fig. 114.—Caversham Bridge: Reinforced Concrete Bridge over the Thames.

If the area to be covered is too large to complete with one mixing, an accurate record of the quantities of materials should be kept in order that there shall be no variation in colour with successive mixes.

The addition of 4 per cent. of calcium chloride to the mixing water will ensure a thorough bond between the wash and the concrete, as the calcium chloride will attract moisture from the air and keep the wash damp until it has thoroughly set.

It must be remembered that the colour will generally differ when the wash is dry from when it is wet, so that if a colour is to be matched exactly it is advisable to cover a small area, or separate panel, and leave it for a few days until it is thoroughly dry in order to ascertain what the finished surface will be.

Hardening Concrete Surfaces

A method of hardening concrete surfaces, particularly applicable to concrete roads and floors to prevent "dusting," is by the use of silicate of soda.

For the silicate of soda treatment, the surface is prepared for treatment by cleaning free from grease spots, plaster, etc., and then thoroughly scrubbed with clean water. To get the best penetration the floor must be thoroughly dry, especially before the first application, and if practical it is well to let it dry for several days after the first scrubbing.

The silicate solution is made up immediately before using (one gallon of commercial water-glass solution is diluted with four gallons of water, and the resulting five gallons will cover 1,000 sq. ft. of floor surface with one coat). The solution may be applied with a mop or hair broom, and must be continuously brushed over the surface for several minutes to obtain an even penetration.

Fig. 115.—Reading Bridge: Reinforced Concrete Bridge over the Thames.

An interval of 24 hours should be allowed for the surface to harden, after which it is scrubbed with clean water and allowed to dry for the second application. Three applications made in this manner will usually suffice. When properly applied the treatment gives a very hard surface that is bright and uniform in appearance.

Painted Surfaces

Any good oil paint may be applied to concrete surfaces providing the concrete is first washed over with two or three copious applications of a

40 per cent. solution of zinc sulphate in order to prevent the paint being affected by the lime in the concrete.

The art of decorating concrete by applying coloured cement is an interesting development of concrete surface treatment, and some extraordinarily good results have been obtained. Decoration applied in this manner need not be confined to conventional or geometric forms, but any kind of pictorial effect may be obtained in this medium. The method is to use coloured mortars which are used instead of paints and applied with brushes, trowels and spatulas.

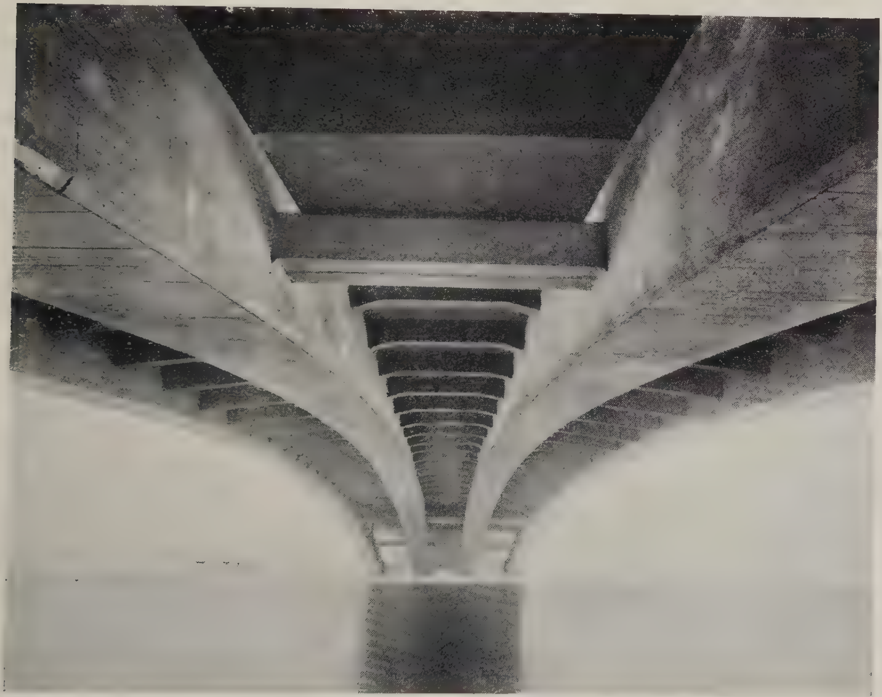


Fig. 116.—Reading Bridge: Underside of Reinforced Concrete Arch.

Moulded Surfaces

Good effects may be obtained by forming a reeded or fluted surface by the use of special shuttering. One of the first large-scale examples of this treatment in this country was at the British Empire Exhibition at Wembley where large unbroken surfaces were relieved by joint marks (see *Fig.* 117). This effect is obtained by nailing strips of wood to the inner face of the formwork, as shown in *Fig.* 118. By this method practically any pattern can be made on a wall, but it is desirable to keep it as simple as possible. Whether the pattern be recessed or raised it is essential that there should be no under-cutting of the forms, or it will be impossible to strip the forms without damaging either the wood or the concrete.

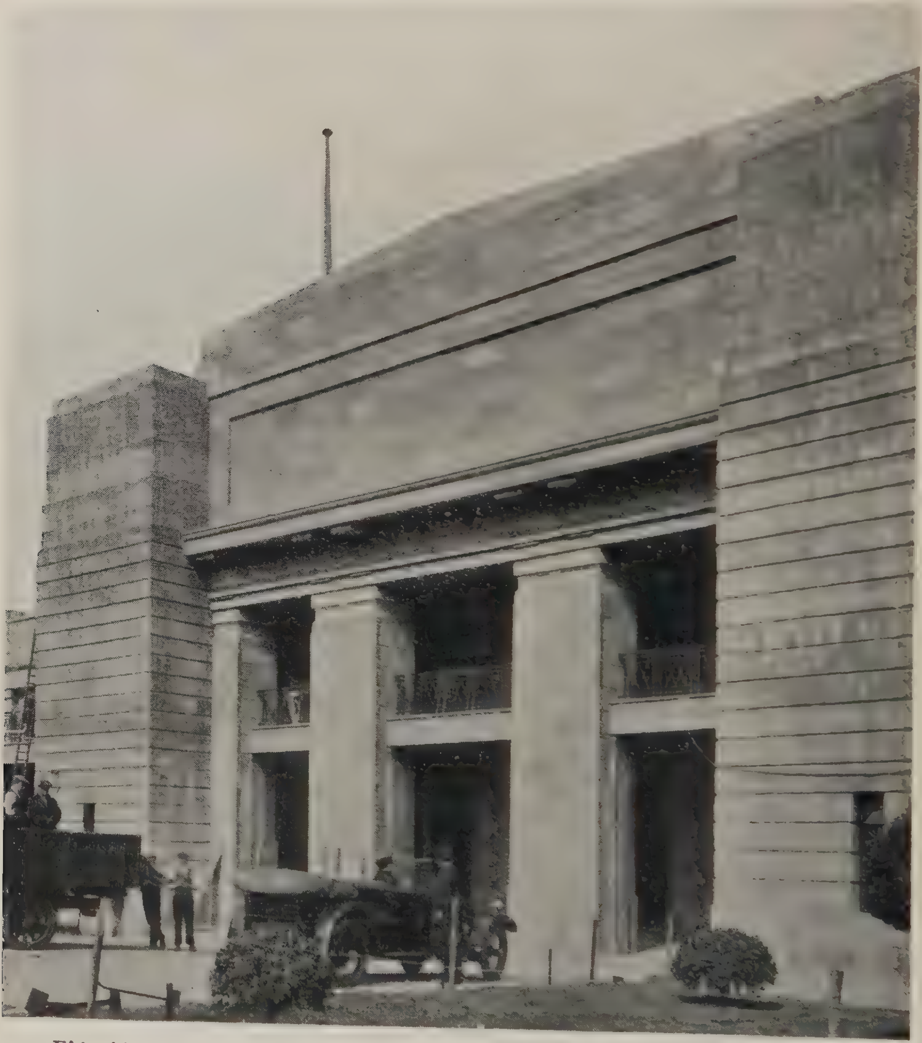


Fig. 117.—Concrete Surface Treatment obtained with Special Forms at the British Empire Exhibition.

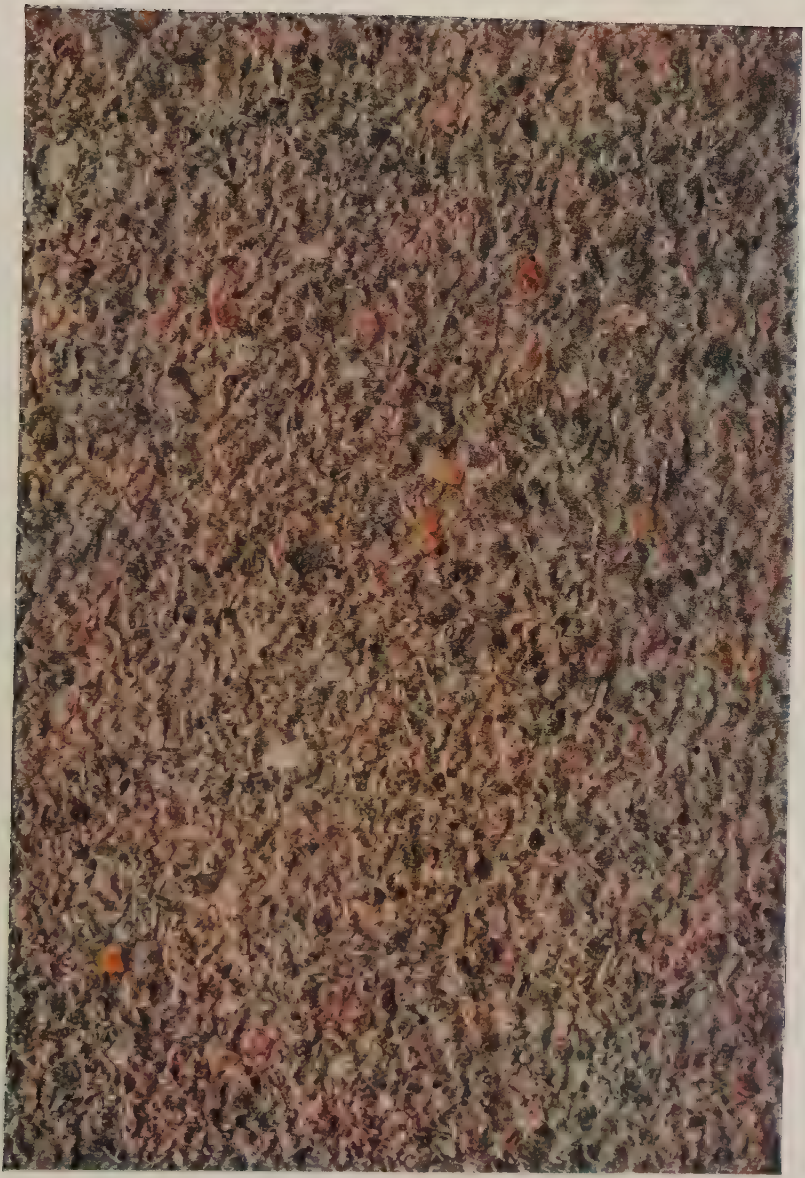


PLATE I.—EXPOSED AGGREGATE—RED AND GREY GRANITE.

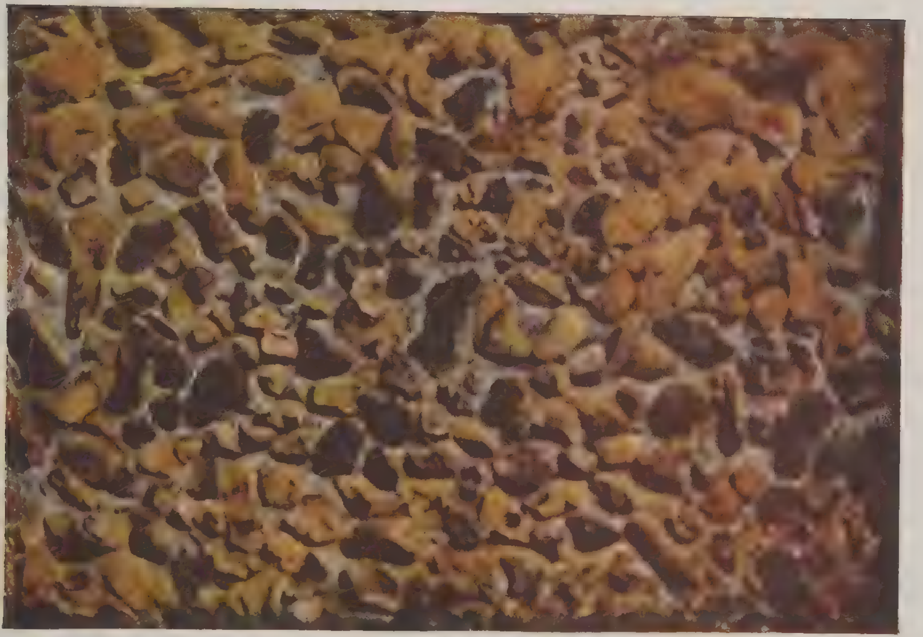


PLATE II.—SCRUBBED CONCRETE SURFACE WITH CRUSHED FLINT AND LIGHT SAND AS AGGREGATE.

PLATE III.—CAST LIMESTONE.

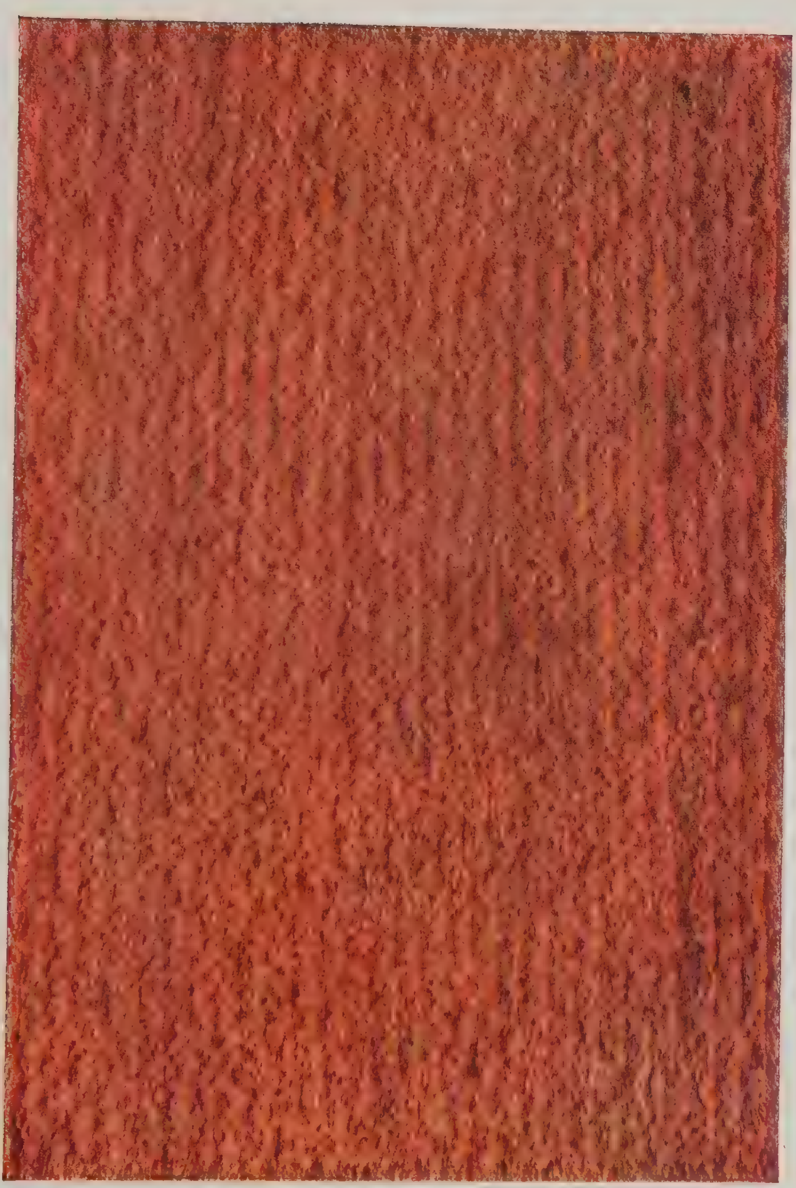


PLATE IV.—CAST RED SANDSTONE.

PLATE V.—PORTLAND CEMENT STUCCO.

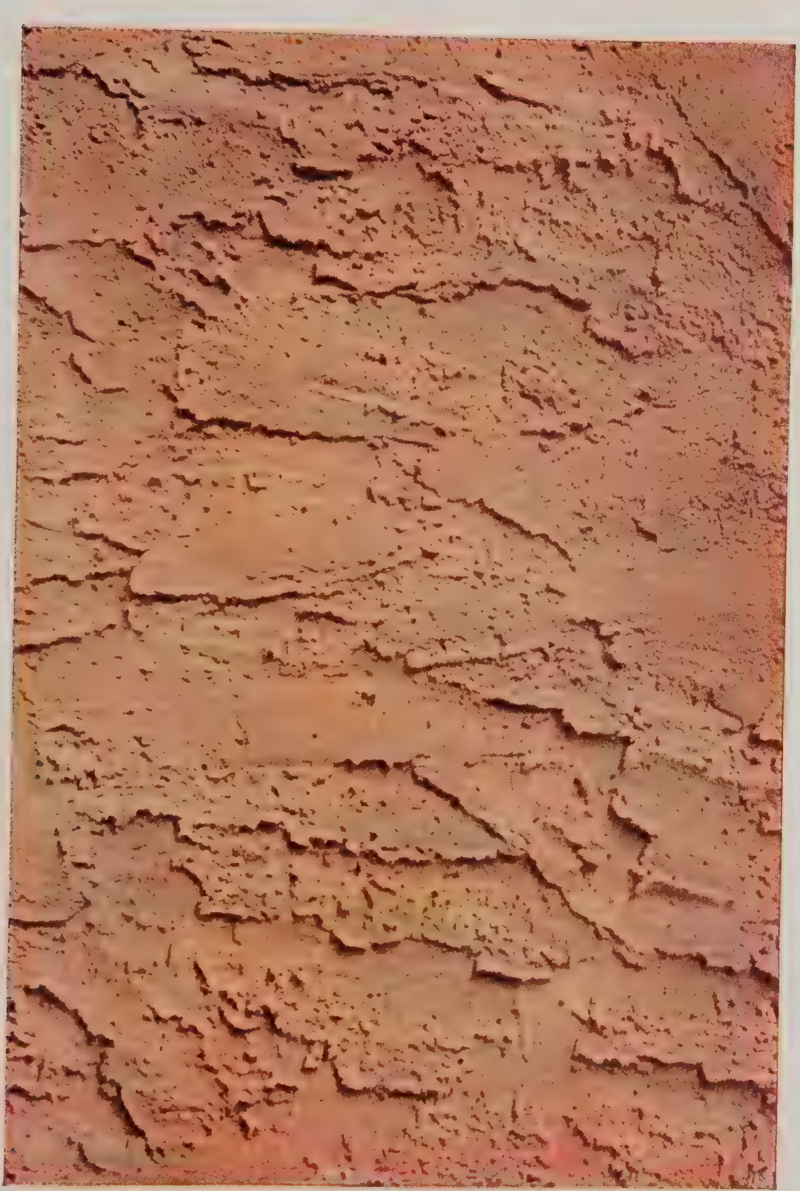


PLATE VI.—PORTLAND CEMENT STUCCO.

Another design carried out with special shuttering is shown in *Fig.* 119. In this case the whole of the ornamental work was formed within the shuttering before pouring the concrete, and the faces afterwards rubbed with carborundum. The total cost of supplying the extra moulds and fixing them in position in the forms and planing and oiling the wood, was £32, including the extra cost of the slightly richer mix used. The cost of cleaning and rubbing down the whole of the front with carborundum was £11.

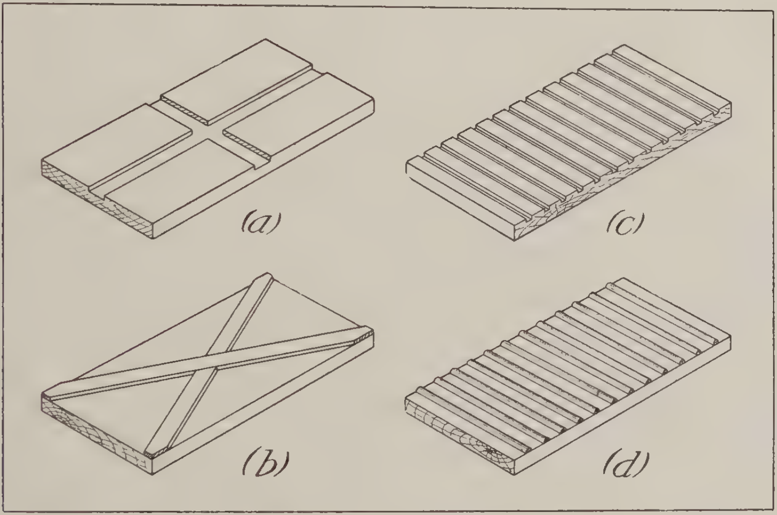


Fig. 118.—Face-Plates.

(*a*) For raised pattern, (*b*) for incised pattern, (*c*) for ribbed face, (*d*) for fluted face.

Cement Rendering

Rendering is the name given to a coat of plaster or cement applied to brick or concrete walls. It is essential that the surface which is to be rendered should be rough; if it is of old brickwork the joints must be raked out. New brickwork is left unpointed if a rendering coat is to be applied later.

The process of rendering with plaster consists in applying a first coat of coarse stuff applied fairly wet and so as to fill up the holes in the wall. The coarse stuff consists of 1 part of sand to 1 of slaked lime and 1 lb. of hair to every 3 cu. ft. of mortar. As soon as this coat has become firm it is floated with fine stuff consisting of slaked lime and hair and brought to level by plaster screeds or dots. Before this becomes quite dry it must be brushed over. The third or setting coat consisting of two parts of fine stuff to one part of fine sand is applied to the floating coat after this has dried out.

When rendering a wall in cement to make it watertight, the surface must be wetted to prevent it taking up water from the cement mortar, and roughened, if it is not so already, to form a good key. The mortar should be in the proportions of 2 of sand to 1 of cement for the first coat and a 1 to 1 mix for finishing. Cement screeds are formed on the surface and the rendering laid on in the thickest practicable coats. If the wall is a basement one the body of it should be as dry as possible before starting the work.

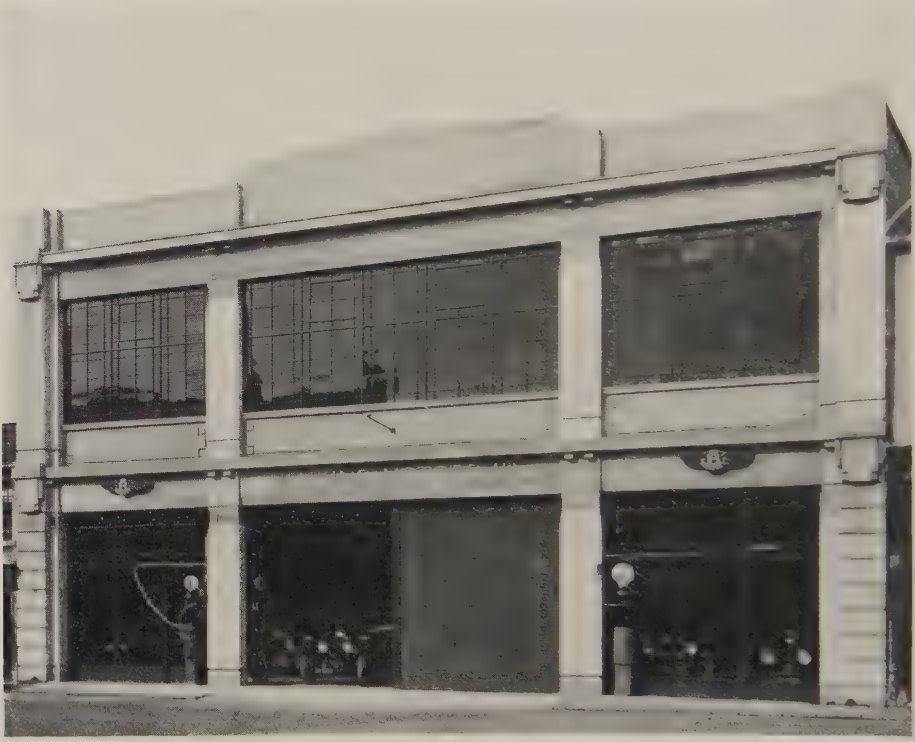


Fig. 119.—Concrete Garage: Architectural Detail Cast in Main Shuttering.

In present-day practice it is usual to employ Hydralime and Portland cement when making up cement mortar for rendering.

Stucco

Perhaps the most attractive weatherproof finish that can be obtained is one or other of the modern cement stucco finishes, which within recent years have been developed in a variety of colours. These stucco finishes are a direct result of the introduction of white Portland cement, and the increasing realisation of the possibilities of coloured Portland cements. The treatment may be applied to walls built of any material with the same co-efficient of expansion and contraction as cement mortar. On most of these walling materials stucco may be applied direct, as they form sufficient key, but if a good key is not obtainable expanded metal or wire mesh may be fixed to the wall.

Before applying stucco the wall must be cleaned of all loose material, and, if necessary, roughened to form a key. In the case of brick and stone walls, the mortar joints should be raked out.

It is also necessary to apply water to the wall (through a hose, or by brushing) until no more will be absorbed ; if this is not done the wall will, according to its permeability, absorb from the stucco the moisture necessary for it to harden properly, with the result that the stucco will be liable to peel or flake. In the case of a concrete wall, if the shuttering can be stripped early enough it is preferable to apply the stucco while the concrete is "green," thus ensuring a stucco surface that is to a certain extent monolithic with the wall.

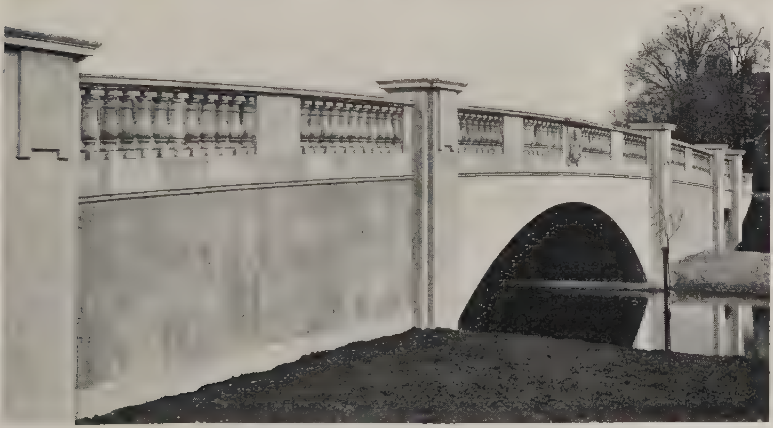


Fig. 120.—Reinforced Concrete Bridge with Cast Stone Balustrade and Ornamental Work.

For best results, three-coat work is recommended. After the wall has been cleaned and wetted (and roughened if necessary), a coat of 1 part ordinary Portland cement to 3 parts sand is applied to a thickness of about $\frac{1}{4}$ in. This first coat is scratched to give a good key for the next, or floating, coat ; horizontal scratching is best, as this helps to prevent the next coat from slipping.

The same mixture is used for the second or floating coat, applied 24 hours after the first render coat. The floating coat is $\frac{1}{2}$ in. thick, and is plumbed and smoothed with a floating rule. This coat should be cross-scratched to give a key for the final coat and left for 30 hours before the final coat is applied; care must be taken that the floating coat will not absorb moisture. The best test is to wet the wall thoroughly and let it stand for ten minutes; if at the end of that time all the water has been absorbed, more should be applied. The wall is ready for the finishing coat when it is still moist 10 minutes after thorough wetting.

The finish coat can be of almost any shade desired, and there is no end to the number of textures that can be produced. The mix for the finish should be 1 part of coloured cement to 3 parts of sand, using sand as near as possible of the same shade as the coloured cement. (A list of materials to use for colouring cement to various shades is given in Part III.) If more than one colour is to be used on the same wall, they should all be mixed in advance.

The colour plates Nos. V and VI show some of the effects possible, but much has to be left to the skill of the plasterer; stucco finishes indeed open up a new aspect of the plasterer's craft, for a craftsman with a knowledge of his materials and an eye to effect can produce an endless variety of textures. After being wedded to the flat surface for centuries, the wall plasterer has an opportunity of imparting his individuality to his work. None of these finishes needs expensive tools. In Plate V different coloured mortars are applied to the surface, worked into each other, and the trowel marks smoothed off until a fairly flat surface is produced. Plate VI shows an effect produced by leaving the rough trowel marks. The texture in both Plates V and VI could, of course, be coarser or smoother if desired.

Often finishes can be produced by stippling with a stiff brush after the finish coat has been trowelled level, by dabbing with the handle of the trowel, by floating with a wood float in a circular direction, and many other methods that readily suggest themselves. Whatever method is used, however, it is essential to employ a skilled plasterer.

A list of suitable sands will be sent on application to the Cement Marketing Co., Ltd.

Efflorescence

There are two types of efflorescence, that caused by alkaline salts differing from the so-called efflorescence consisting of calcium carbonate, and it is the latter which is the principal cause of trouble in this direction. Every concrete surface has a film of carbonate of lime, but usually so thin as to be unnoticeable except in cases where the concrete is porous and lime can be dissolved out of the core of the concrete and brought to the surface by capillary action. This is the reason why efflorescence is more often seen on badly made and porous concrete. This efflorescence is present whether colouring materials are used or not. It shows up more on coloured concrete, but is present more or less on all concretes. Efflorescence may be washed off with clean water or dilute hydrochloric acid.

PART IV

PRACTICE

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PRACTICE

Setting Out the Work

IMPORTANT works are set out by means of a theodolite for ranging in the centre-lines and an engineer's level for setting pegs to indicate the depth to which the excavation must be taken out and the finished level of the concrete.

Minor works and the smaller portions of large contracts are set out by pegs or spikes and lines. It is important to keep all the pegs and lines clear of the excavation, else when the latter is being taken out they will be disturbed and must be set out again. If, for example, a ground floor slab is to be 36 ft. by 20 ft. in area, the pegs may be driven in such a position that the lengths of the sides of the rectangle formed by the lines are 44 ft. by 28 ft. or some less dimensions which will ensure that the pegs will not be covered by excavated spoil. The lines should run round the pegs as shown in *Fig.* 121, and if wooden pegs are used they should not be less than 1½ in. square. In case pegs may be disturbed it is as well to surround them with a few shovels of concrete.

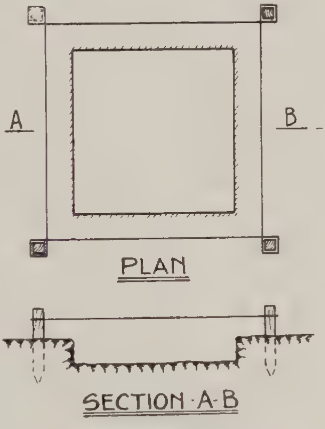


Fig. 121.

To indicate the top surface of the finished concrete floor, pegs are driven in with their heads a foot or so above the required finished level (*Fig.* 122). It is then an easy matter to measure one foot down from the top of two adjacent pegs and finish the surface between to the level shown by means of a board.

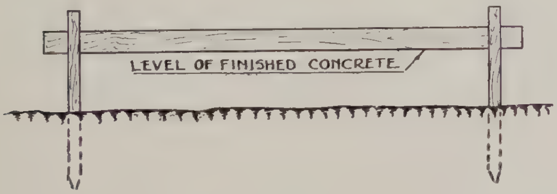


Fig. 122.

Reference marks, well outside the site of the structure, will be helpful in ascertaining the positions of pegs which have been lost or checking them from time to time to see if they have been disturbed. Reference marks may be cut on existing ironwork or stonework with a cold chisel.

Foundations

The foundations of a building transmit the loads carried by the structure, including its own weight, to the soil beneath. Owing to the monolithic nature of a reinforced concrete building a slight settlement at one point is not likely to cause disaster, as the danger of collapse is minimised when compared with the older types of construction, but this does not mean that any lack of care is permissible when dealing with foundation work.

There are many points to be considered when designing foundations, and among the principal are the following:

(1) The safe resistance of the soil.
(2) The atmospheric influence on the soil.
(3) The size, shape, and strength of the foundation to give proper distribution of load, and
(4) The possibility of the withdrawal of water or soil during future work in the vicinity.

Safe Resistance of Soil

The safe resistance of the soil is the first factor to be considered, because this will determine the area over which the load must be distributed, and the object of the foundation will be to spread this load over an area sufficiently large to prevent a pressure at any point greater than that which the soil can safely bear. In the regulations of the London County Council it is stated that the pressure of foundations on the natural ground shall not exceed the following:

Natural bed of soft clay or wet or loose sand—1 ton per sq. ft.
Natural bed of ordinary clay or confined sand—2 tons per sq. ft.
Natural bed of compact gravel, London blue clay or chalk—4 tons per sq. ft.

As an example, if we assume a reinforced concrete column carrying a load which together with the weight of the foundation totals 100 tons, the area of the base must be sufficient to spread this load so as to keep the pressure per sq. ft. within the limits given above; if the foundation is in soft clay the base must be 100 sq. ft. in area, or, say, 10 ft. square. For ordinary clay 50 sq. ft. is necessary or a base just over 7 ft. square, and for compact gravel an area of 25 sq. ft. is required, which will be given by a base 5 ft. by 5 ft.

Influence of Atmosphere on Soil

The second point is the influence of the atmosphere on the soil, and while this is not so important as the safe resistance of the soil it is an item that must be considered. The weather conditions and the atmosphere generally affect the soil below the surface as well as the surface of the ground itself, and if the foundations are not carried down below the level of the atmospheric influence they will be subject to varying conditions which cause movement and possible settlement.

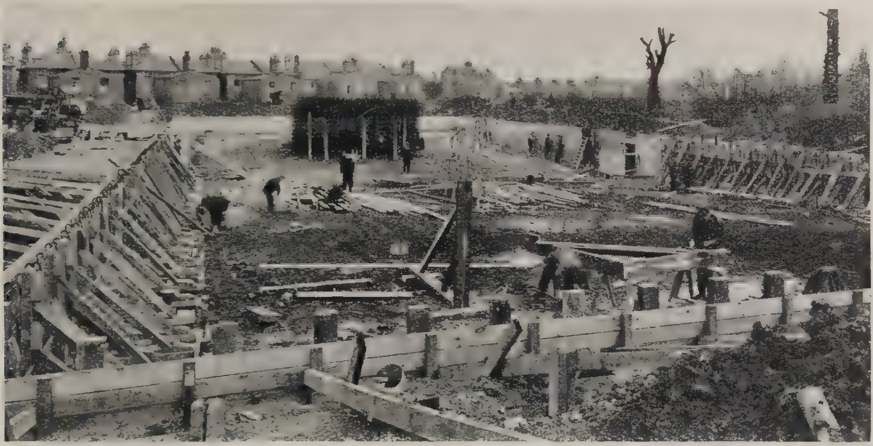


Fig. 123.—Hornsey Swimming Bath during Construction.

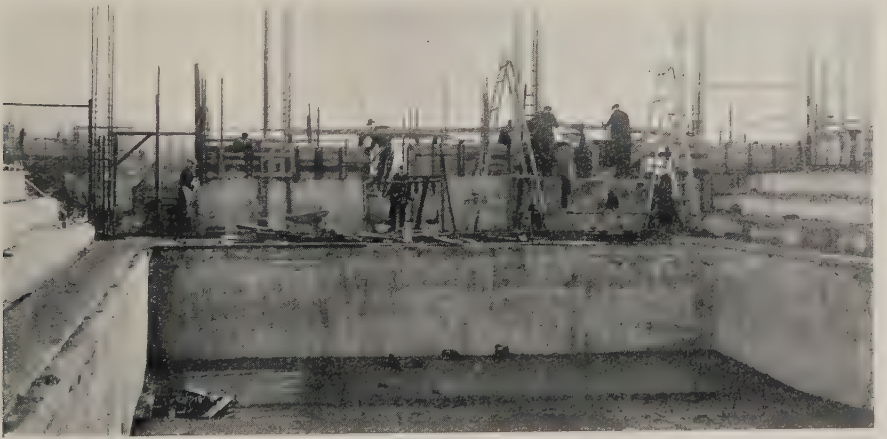


Fig. 124.—Dudley Corporation Public Baths, showing Pond after Removing Formwork.

The level of the limit of atmospheric influence in this country is generally reckoned at about 3 ft. from the surface, and this is therefore the minimum depth to which the foundation should be taken when dealing with work of importance. The action of the atmosphere is liable to be more pronounced in some soils than in others. In a clay soil, for example, in summer the soil will usually contract considerably, and cracks will occur on the surface and extend downwards, while the atmospheric conditions in the winter will cause the clay to swell again ; the soil is therefore constantly on the move.

Frost also causes moisture in the soil to expand, and when a thaw sets in contraction will follow ; this results in a movement down to the level of the limit of the atmospheric influence. The action of the expansion of the soil during frost is well illustrated in the case of a road surfaced with slag or water-bound macadam, as when a thaw occurs the surface will be found to have become broken up, and generally disintegrated owing to expansion causing the particles to separate.

The importance of this factor in foundation work will depend so much on circumstances that no general rule can be given other than the taking down of the bases of all columns so that the underside is below any possible movement of the soil caused by changes of atmosphere.

Raft Foundations

When it is necessary to erect a reinforced concrete structure on " made " ground it is important to design the foundation with due regard to the conditions of the site, because " made " ground will usually have a poor bearing capacity and it is also liable to sink. Unless " made " ground is exceptionally deep it is advisable to carry all the weight-carrying foundations down to the solid natural soil, but in some cases where the " made " ground is well consolidated and the structure is not of a heavy type the loads can be distributed by means of a raft foundation. This raft will consist of a large reinforced concrete slab constructed over the whole area of the building, and having reinforced concrete beams or ribs at intervals to divide the slab into panels. By this method the loads will be distributed over a large area and one portion of the building cannot settle without the remainder. If the raft is properly designed to distribute the loads and executed in accordance with the drawings there is no fear of a break taking place. (See also page 132.)

Contraction Joints

It is a well-known fact that improperly designed and constructed concrete work is liable to show cracks due to temperature and shrinkage effects : while these may be to a large extent avoided by keeping the concrete damp during the period of hardening, such precautions are not sufficient if the design is defective.

Cracks are most likely to occur at construction joints where a good bond between new and old concrete has not been secured by a thorough cleansing of the old surface. In order to prevent cracks of irregular outline in walls, vertical stop-boards should be inserted at the ends of each period of concreting; a metal strip should be cast with one half in the concrete, the other half being bent into the jointing material and cast in the remainder of the wall when concreting is resumed (*Fig.* 125).

Where a beam is to be simply supported on a cantilever bracket, sliding plates (*Fig.* 126) are essential between the two concrete surfaces in such structures as gantries, else a portion of the bracket may be broken off owing to the friction between the two concrete surfaces. In building work the joint may be of felt.

Joints of beams over beams or over a wall should be arranged with sliding surfaces either of strong building paper or very thin metal sheeting (*Fig.* 127).

Where traffic is to pass over the joint an angle-iron may be bolted to the corner of one slab and an angle with a plate riveted to it bolted to the other slab. The plate is arranged to slide over the first-named angle (*Fig.* 128).

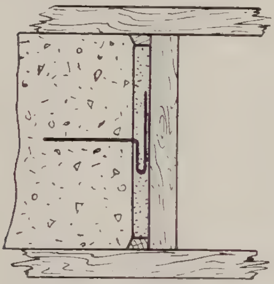


Fig. 125.

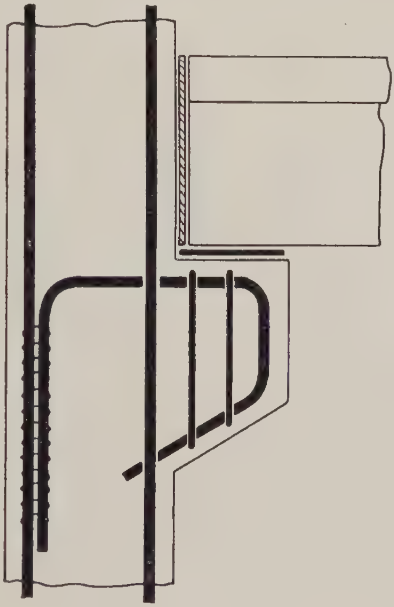


Fig. 126.

Joints in roof slabs may be covered with a ridge roll or with zinc flashing (*Fig.* 129), fastened down to pieces of timber on each side of, and parallel to the joint. If the roof slab is covered with roofing felt the latter can be arranged in the form of a ridge roll over the joint. Such a method allows for considerable expansion and contraction movement.

Long buildings require to be divided completely at intervals by expansion joints, a common method being to duplicate the columns where the joints occur. Reinforcement should never be run through expansion joints. In coal hoppers in order to prevent leakage of fine coal the joint may be filled with a loose angle-iron.

In light retaining walls it is advisable to have joints at every 30 ft., although much longer spacing has been adopted in some cases. The joints may be filled with bituminous materials such as are used in concrete road construction. In culverts, etc., bitumen joints are very useful since they may be used to keep the structure watertight.

The steel required to resist shrinkage stresses and prevent large cracks should not be less than $\frac{1}{5}$th of 1 per cent. of the area of the concrete cross-section, and should be in the form of very small bars. Temperature steel should be lapped for a length of 25 diameters but not hooked, as hooks tend to localise temperature cracks and thus defeat the very object with which the steel has been inserted.

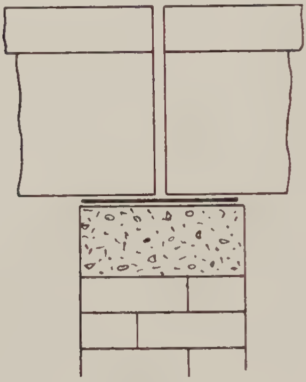


Fig. 127.

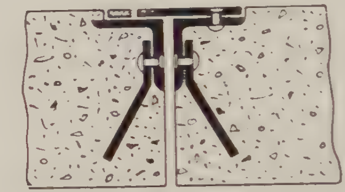


Fig. 128.

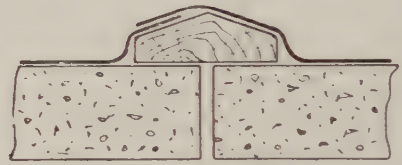


Fig. 129.

Action of Chemicals on Concrete

Owing to the possibility of chemical action between the constituents of concrete and the materials stored in tanks it is sometimes necessary to provide protection by asphalt, water glass or other coatings so that the concrete may not be injured.

The organic compounds classed as "paraffins" and mineral oils, such as petrol, benzine and lubricating oils, are harmless, but the latter oils have a penetrative effect. Penetration by lubricating oils may be resisted by treatment with Kessler fluates. Alkali solutions are harmless to concrete.

With the exception of oxalic acid, which is almost harmless, acids, including fatty acids and oils such as linseed, palm, rape, etc., are harmful. The only salts which produce injurious effects are magnesium sulphate (in sea-water), copper pyrites and other sulphates and magnesium chloride. Among the protective coatings which have been used with success are: coal tar, pitch, cement and paraffin for molasses tanks; lead, asphalt or tiles laid in litharge for sulphuric acid tanks, and glass plates in fruit-juice containers.

Proofing Concrete

A porous concrete would obviously be useless in resisting the penetration of water. A porous concrete has a low density or weight per cubic foot, therefore a dense concrete is required in structures which are to be waterproof. Porosity or honeycombing may be caused by poor grading of the materials used as aggregates, by the use of too little mixing water or by excess of water, and by lack of care in ramming and rodding the concrete. Other causes of leakage of water through concrete are (1) lack of care in making the junction between old and new concrete so that a proper bond may be obtained and (2) rapid drying out of the concrete, owing to improper curing, producing shrinkage cracks.

There are four methods of making a watertight concrete structure: (1) by using a dense, properly-graded and mixed concrete carefully rammed and protected against rapid evaporation of the water in the presence of sun or drying winds, (2) by using one of the special materials which are on the market, and are added to the water or to the cement, (3) by rendering the surface with a mixture of cement and waterproofing agencies, and (4) by covering the concrete with a sheet of paraffin wax or of bituminous material such as hot asphalt or hot coal-tar and pitch applied on the face of the structure which is in contact with the water. The last method is the usual practice when tanks are constructed to resist high heads of water. In ordinary cases the first method will prove satisfactory, and it is noteworthy that an excess of cement is generally more useful than the addition of any other material to the concrete. No added material can make poor concrete wholly watertight; nor can any addition of waterproofing compounds

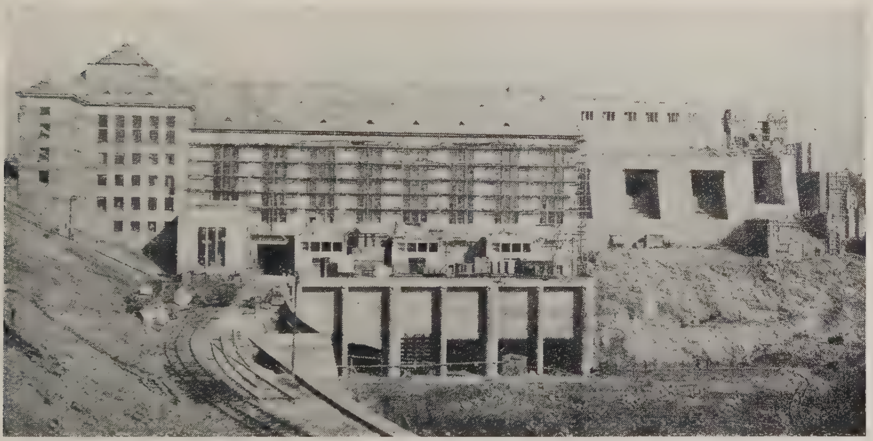


Fig. 130.—Reinforced Concrete Power Station on the Shannon Hydro-Electric Scheme.

compensate for poor workmanship. The addition of inert materials such as felspar, diatomaceous earth, etc., decreases the permeability of the concrete, but the same result may be obtained by increasing the amount of cement used. "Hydralime" (completely hydrated lime) added to the cement in the proportion of 10 per cent. by weight produces satisfactory results.

Coating of defective surfaces has been tried with cement rendering, but the lack of success is due to the difficulty of securing a good bond between the rendering and the hardened concrete. If neat cement be used the new surface is certain to contain shrinkage cracks. The Sylvester process—coating the concrete with a solution of 2 ounces of alum per gallon of hot water followed by a solution of 12 ounces of Castile soap in one gallon of hot water, both washes being maintained at a temperature of at least 100 degrees Fahrenheit—has been used with success.

Mass Concrete

At the present time the name mass concrete is often misapplied to any kind of concrete which is unreinforced no matter how thin the sections may be. In thin walls such concrete is better described as plain concrete, leaving the term mass concrete to denote that class of work which is a feature of heavy dams and in which large blocks of stone, known as "displacers" or "plums," with flat beds and weighing up to 8 or 9 tons each, are set on a layer of concrete mixed in the proportions of 1 : 2 : 4 or 1 : 2 : 5. The coarse aggregate in the latter is often crushed quarry spalls broken to pass through a 1½-in. or 2-in. ring.

For placing plums in a dam a cable slung across the valley is the most usual type of plant. Very large plums are suspended by tongs or chains from the cable. Smaller plums are transported on flat trays hanging from the ropeway. The bed of concrete on which the plums bear should not be too thin and the plums should be laid with broken joints and with sufficiently large spaces between them in the vertical joints to allow the concrete to be thoroughly rammed around them.

DETAILS OF CONSTRUCTION

Column Footings

Formwork.—Square or rectangular footings consisting of a block of reinforced concrete in good stiff ground may be constructed without formwork, the excavation being taken out to the net dimensions only. If the ground is poor the forms which are then necessary consist of hollow boxes two sides of which only need be cut to dead lengths, odd lengths of timber being used for the opposite sides. The boards are held in place by strut and pegs driven into the soil or braced off the excavation by timber or heavy stones.

If the top of the footing is pyramidical (*Fig.* 131) and the slopes are greater than about 25 degrees it may be necessary to anchor down the forms to the sloping sides. This can be done by using wire ties connected to the main reinforcing mat, old pile-heads, heavy stones, timber, etc.

Some engineers prefer to use stepped footings (*Fig.* 132). This type requires less concrete than the solid block footing, but the saving in concrete is offset by the extra steel required.

Concreting.—Isolated footings are generally concreted from a portable mixing plant since the chuting plant, if one is to be used on the remainder of the contract, will not usually have been erected so early.

Stepped footings should be concreted in one operation and a joint not left at the step, else they cannot act in the manner in which they have been designed, the effective depth being very much reduced.

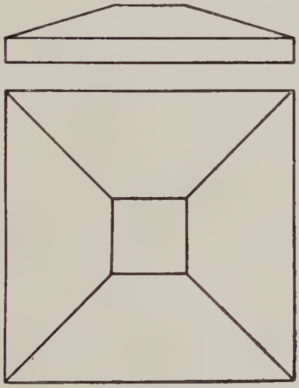


Fig. 131.

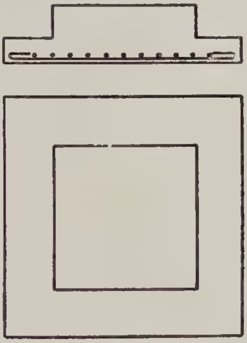


Fig. 132.

Reinforcement.—All bars in footings should be provided with hooks since the bond stress is usually high. The mat of bars forming the footing reinforcement should be wired together on the bench, tying the intersections with 16 or 17 S.W.G. soft iron or annealed steel wire, and placed in position as a unit. All wiring of bars should be done on the "over and under" principle (see p. 69), which is the best way of securing a rigid connection.

Where a large number of similar footing-mats have to be put together a jig of some kind should be made on the steel bender's bench to facilitate assembling the bars. A simple way is to nail lightly two lengths of 6-in. by 2-in. timber on edge and spaced at a distance of about 4 in. greater than the interval X (*Fig.* 133) between the two outer bars running in one direction. Between these 6-in. by 2-in.'s run another shorter pair in a rectangular direction. Two-inch nails, in pairs and close enough to allow a bar to drop between them, are driven into the 6-in. by 2-in.'s wherever bars are required to cross them. With such an arrangement the intersections of the bars, where the wiring takes place, will not be fouled by the timber, and the work of wiring will be more expeditious than if the bars are laid direct on the bench and have to be lifted each time a tie is put in place.

Some contractors assemble the footing cages in the form shown in

Fig. 134, while others insert two meshes of steel in all footings with the lighter mesh on top.

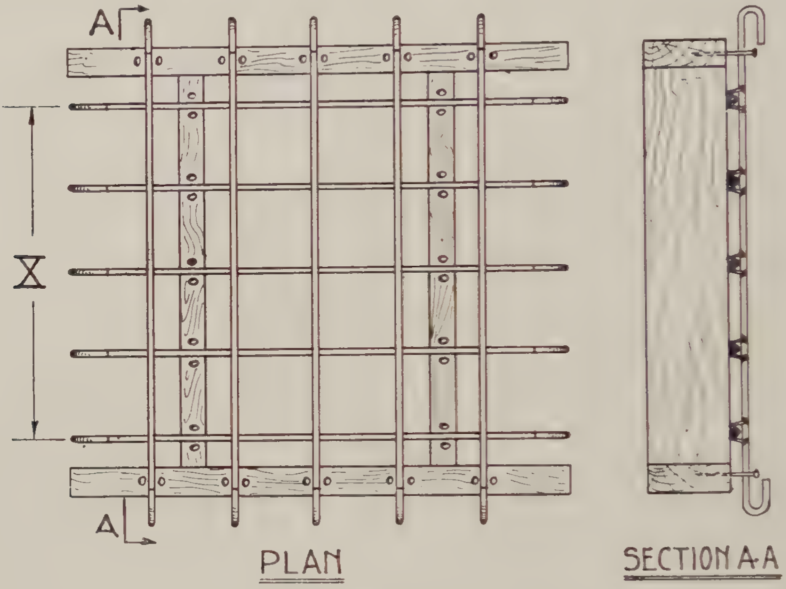


Fig. 133.

The foundations for walls as distinct from columns will depend entirely on circumstances, but generally speaking the walls in a reinforced concrete structure are not designed to support heavy loads, and the wall foundations are therefore of minor importance. The loads are transmitted to the columns and piers by reinforced concrete beams when the soil is of poor bearing capacity. In the case of retaining walls the foundations are designed in

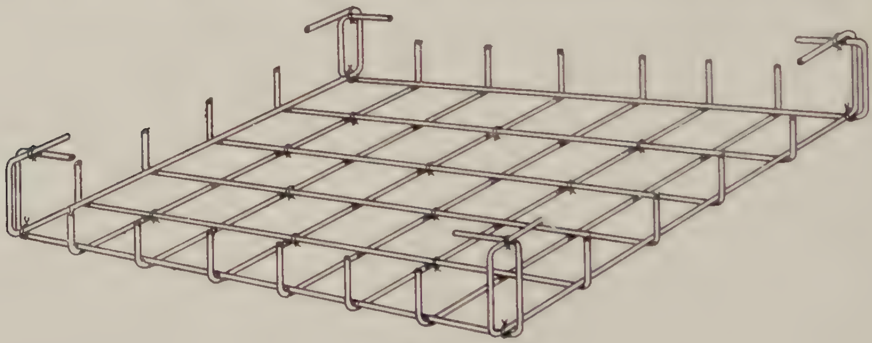


Fig. 134.

conjunction with the vertical portion of the wall; and these do not come under the ordinary heading of bases or foundations.

Slab Foundations

In industrial works cast-iron or steel tanks are often supported on reinforced concrete slabs which distribute the load over the ground. For purifier boxes in gas-works, gas-holder or oil-pressure tanks this is a very economical type of construction. On fairly good ground an 8-in. slab with mesh reinforcement is commonly used, the proper amount of reinforcement per sq. yd. and thickness of slab are, however, matters which can only be decided by an engineer skilled in this type of work. At the edges of the slab it is usual to introduce a stiffening ring under the main slab; this is particularly necessary when the superstructure is a gas-holder tank with one or more lifts, the load from which is transferred to the ground through a series of rest-blocks supported on the periphery of the slab (*Fig.* 135). In this case the stiffening ring acts as a continuous circular beam loaded by the upward acting soil-pressure, the reactions being provided by the rest blocks.

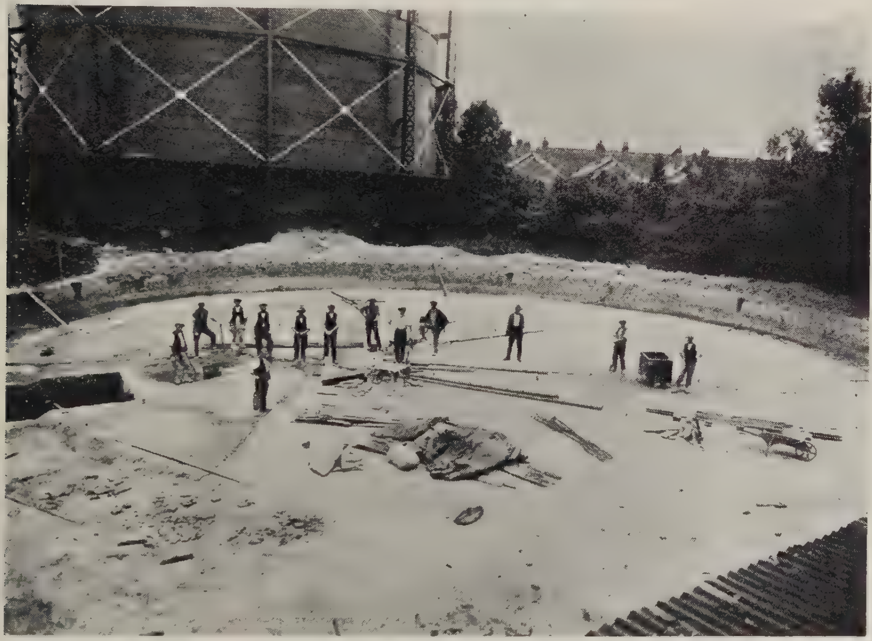


Fig. 135.—Reinforced Concrete Gas-Holder Foundation at Haywards Heath.

Formwork.—Except for the walls of the pipe-pits the only forms required are those at the outer edge of the stiffening ring where a 1-in. or $1\frac{1}{2}$-in. board on edge, held in position by stout pegs, must be provided.

Concreting.—The plant required is a stationary mixer, feeding barrows, concrete carts or jubilee skips. Any more elaborate arrangement such as a mast is generally prohibitive in cost owing to the small yardage of concrete to be poured. With circular slabs great care must be exercised in screeding off the surface of the concrete since this is often required to have a slope of 6 in. from the inner edge of the ring to the centre of the slab. A truly conical surface is very difficult to secure and it is generally permissible and much less costly to make the finished surface polyhedral. If the holder is of the spiral-guided type the surface of concrete in the ring must be level to prevent binding in the bearings when the holder is in operation.

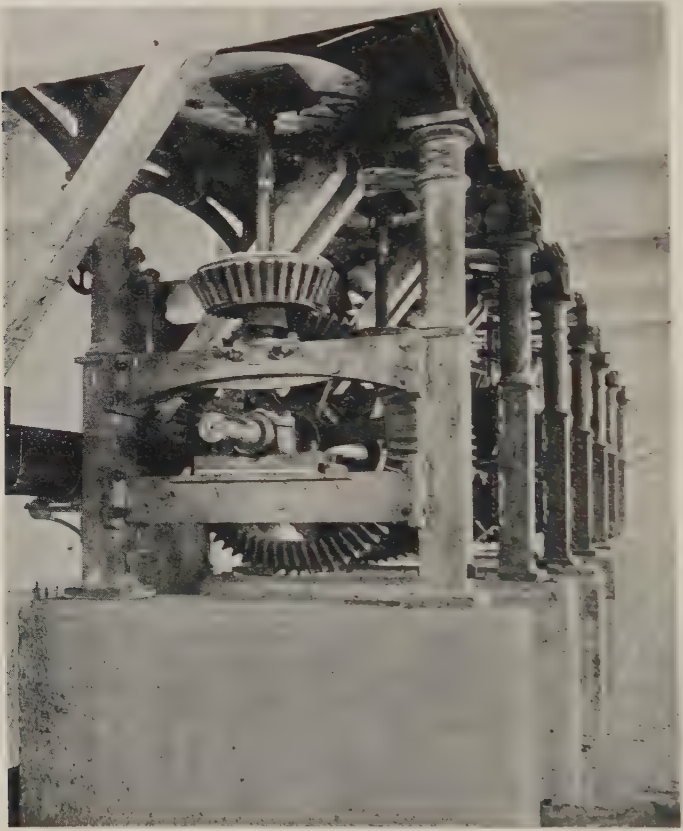


Fig. 136.—Milling Machinery on Concrete Foundation at Swansea.

Load on floor, 11 cwts. per sq. ft. The floors are remarkable for absence of perceptible vibration. This view was taken 13 years after erection.

Machinery Foundations

Light machinery foundations are constructed by bolting 3-in. or 4-in. timber down to the concrete floor, the machines themselves being fastened down to the timber with coach screws. Machinery running at high speeds should be bolted directly to a concrete foundation on which timber has been laid to cover the space occupied by the bed-plate.

Heavy machine foundations (*Fig.* 136) consist of one or more blocks of concrete suitably boxed out where the holding-down bolts are to be placed. The concrete should be poured to within ¾ in. of the finished level and allowed to harden. The machinery is then lowered on to steel wedges and grout run in under the bedplate. As soon as this has hardened the wedges may be released and the openings left grouted up. Foundations subject to heavy impact such as those for steam hammers must be covered with one or more layers of heavy pitch-pine bolted together.

Turbo-generator foundations which were formerly constructed of mass concrete and steel joists are nowadays invariably built of reinforced concrete which has proved to be unaffected by the vibration caused by these machines and much less costly than the older type of foundation.

Pre-cast Block Foundations

In the construction of the Trafford Wharf on the Manchester Ship Canal a double length of pre-cast reinforced concrete boxes, mounted on two rows of reinforced concrete cylinders sunk in the slope of the canal, was used for the construction of the wharf. The internal and external forms for the boxes (*Fig.* 137) were of steel. The boxes are 25 ft. long, 11 ft. wide and 9 ft. high and weigh 57 tons each.

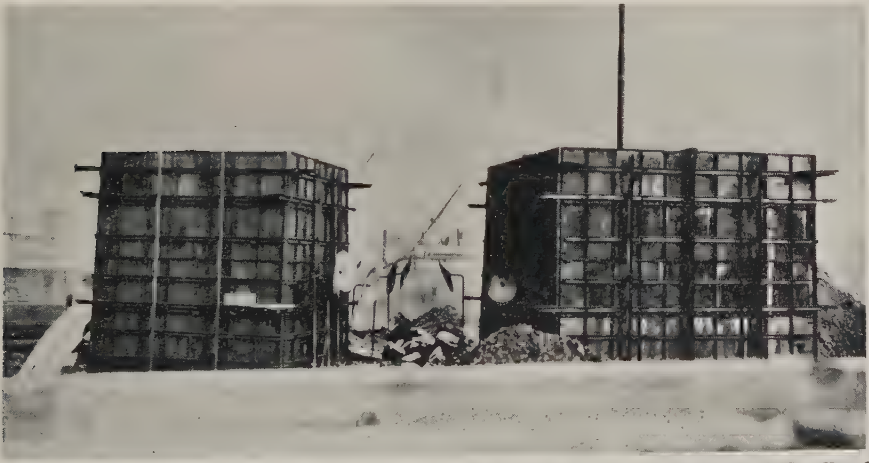


Fig. 137.—Steel Forms made up ready for Concreting Foundations of Trafford Wharf, Manchester Ship Canal.

Trestle Foundations

Even when the supports of conveyors consist of steel trestles a large saving of expense in constructing the foundations can be secured by the employment of reinforced concrete. The usual type of trestle foundation (*Fig.* 138) consists of a pair of square or rectangular footing slabs surmounted by blocks sufficiently long to take the holding-down bolts and connected by a transverse beam. If there is any danger of uplift the footings must be buried to such a depth that the earth above the concrete combines its weight with that of the latter to balance the uplift with the desired factor of safety. No difficulty is met with in constructing such foundations but it is important that the bolt holes be boxed-out since if the bolts are cast-in solid there will be no play available in case the steelwork is not exact to dimensions. Wherever the positions of two or four bolt holes are to be marked out a template should first be made and the centre of this set accurately in position. The formwork and reinforcement are similar to that described on page 126 for square footings.

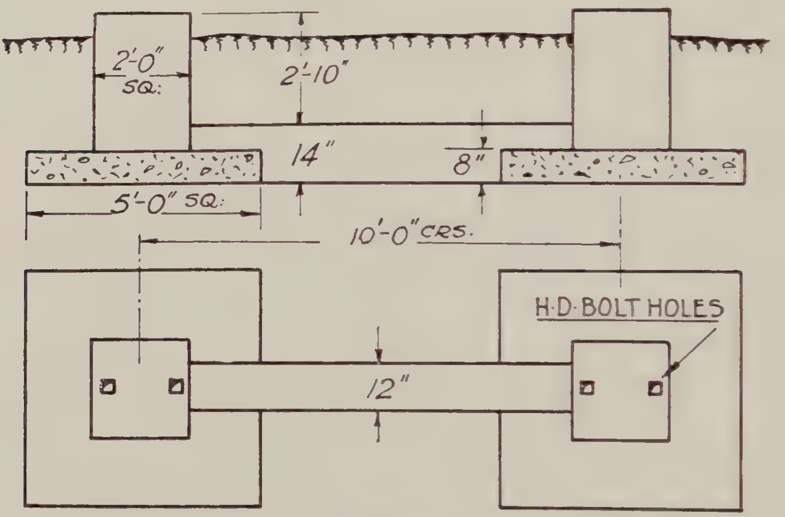


Fig. 138.

Raft Foundations

Before the introduction of reinforced concrete the construction of foundations on sites where the ground was of poor bearing capacity almost always necessitated the employment of timber piles reaching down to a firm stratum, or piles or cylinders which transmitted their loads to the surrounding soil by friction. In many cases the cost of such foundations

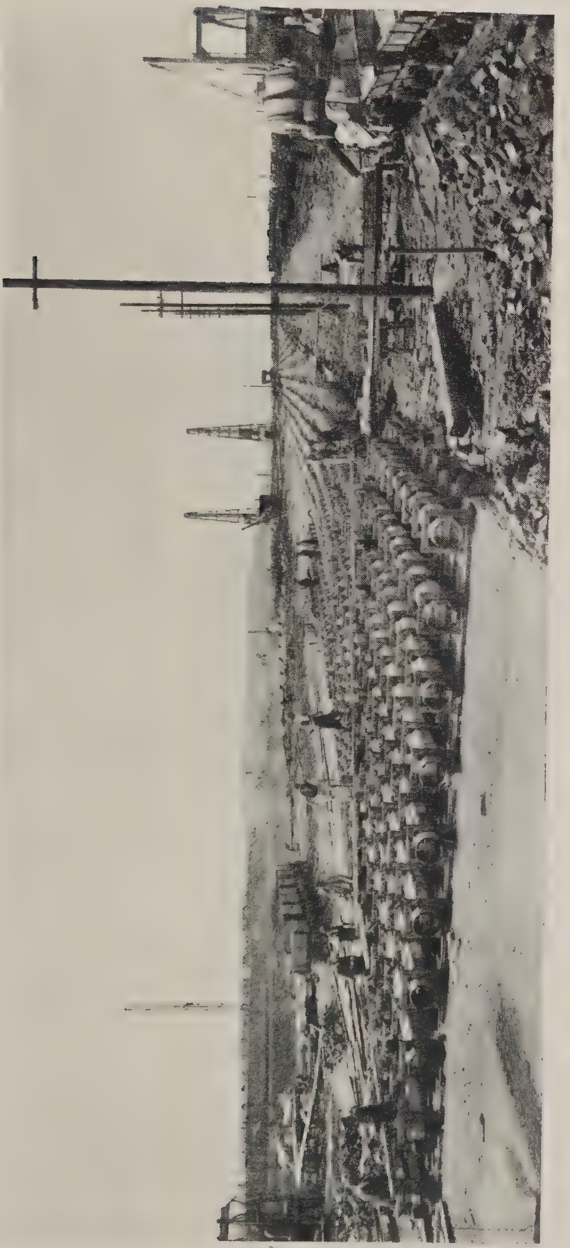


Fig. 139.—Piles for Shed Foundation, Gladstone Dock, Liverpool.

was prohibitive until the reinforced concrete raft was found to be a possibility. At first thought it might appear impossible that a building with column loads, each of several hundred tons, could be supported on a floating raft of concrete resting on material with a carrying power of less than 10 cwt. per sq. ft. There are now many examples of this type of foundation on ground which can only be described as silt.

A reinforced concrete raft is somewhat analogous to an inverted floor loaded by the upward pressure of the ground ; it is however a structure which requires great skill and experience in its design and this should in all cases be entrusted to an engineer who has specialised in this type of foundation. Any error in design is likely to cause serious trouble and may even cause the raft to "break its back."

A very common form of raft is constructed with inverted tee-beams the ribs of which project above the floor. Where the floor is required for working or storage purposes these ribs are objectionable. A second floor may then be constructed above the first, thus forming a hollow box or the spaces between the ribs filled in with broken brick, clinker, etc. In some cases the raft is of a simpler type (*Fig.* 140) which is a development of the continuous strip footing.

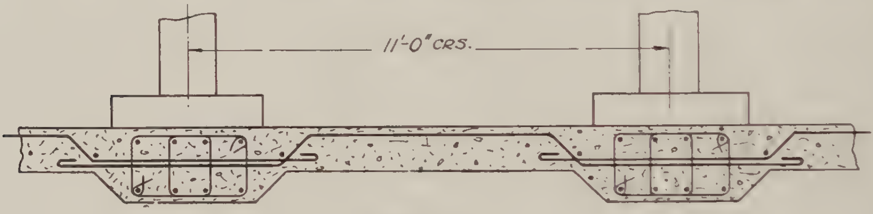


Fig. 140.

Piles

Omitting steel piles which have only a limited use the only competitor with reinforced concrete is the timber pile which is gradually giving way on account of its numerous disadvantages. Timber piles are inferior to reinforced concrete because they (1) cannot resist decay at points above subsoil water level, (2) are useless in resisting *Teredo navalis* and other boring organisms, (3) entail extra cost in building heavy footings and (4) cannot be obtained in the required sizes. Pre-cast piles have been driven over 110 ft. in length and 24 in. by 24 in. in cross-section.

When a piled foundation is necessary the ultimate load which a pile of any size will carry may be calculated from one of many formulae. This load depends on the weight of the hammer or monkey and its height of fall, the weight of the pile and the "set" or average distance through which the pile sinks under each of the last five or ten blows of the hammer. Piles may carry their load either entirely on the shoe, acting as a column, by lateral friction between the pile surface and the surrounding ground or by a combination of these two actions. The reinforcement must be designed so that the pile may act as a column at points where it is unsupported and will not crack when being lifted to the pile frame.

Formwork.—The casting-yard (*Fig.* 141) is often covered with a layer of 2-in. or 3-in. planks which form the bottom of the pile shutters. To this bevel strips are nailed at the distance required to form the chamfers on the pile. The side forms for square piles are of 1½-in. or 2-in. boarding braced by 4-in. by 2-in. cleats and tied together at the top by 4-in. by 2-in. timber or clamps. Temporary struts are placed in the bottom of the forms to keep them apart and are knocked out as concreting progresses. Special end pieces are required to close the form at the tip and butt of the pile. In some cases the first row of piles is cast with spaces arranged between them so that when the side forms are removed the sides of the piles act as forms for the piles to be cast in the intervening spaces.

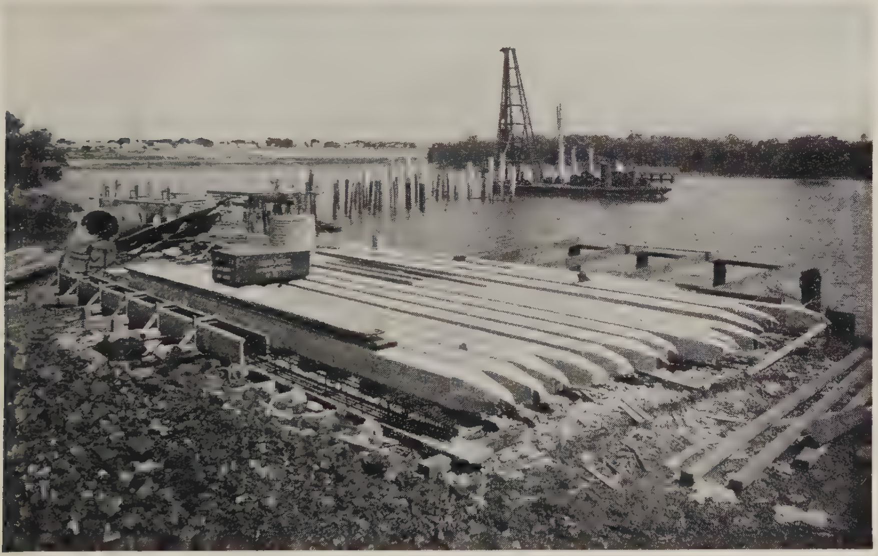


Fig. 141.—Reinforced Concrete Piles Ready for Driving.

Concreting.—For small numbers of piles the only available method is to pour the concrete from barrows travelling on runways between the forms. On large jobs a chuting plant or a travelling crane is often used, the type known as a traverser being the most useful. The mix used in Great Britain is often 1 : 1½ : 3 but 1 : 2 : 4 has proved satisfactory provided the cover on the main bars is not less than $1\frac{1}{2}$-in. Many engineers specify granite aggregate for piles, but other aggregates can often be used with safety. The time for stripping the forms depends on the kind of cement used. Piles must not be moved until they have hardened thoroughly and should be kept damp while this is going on. With the ordinary brands of cement piles should not be driven until they are at least a month old, but with rapid-hardening cement this period may be reduced to a few days. *Fig.* 139 shows the lay-out of the casting yard at the Gladstone Dock, Liverpool, where octagonal reinforced concrete piles were used. The concrete mixer is on the right-hand side of the illustration and the pile drivers in the background.

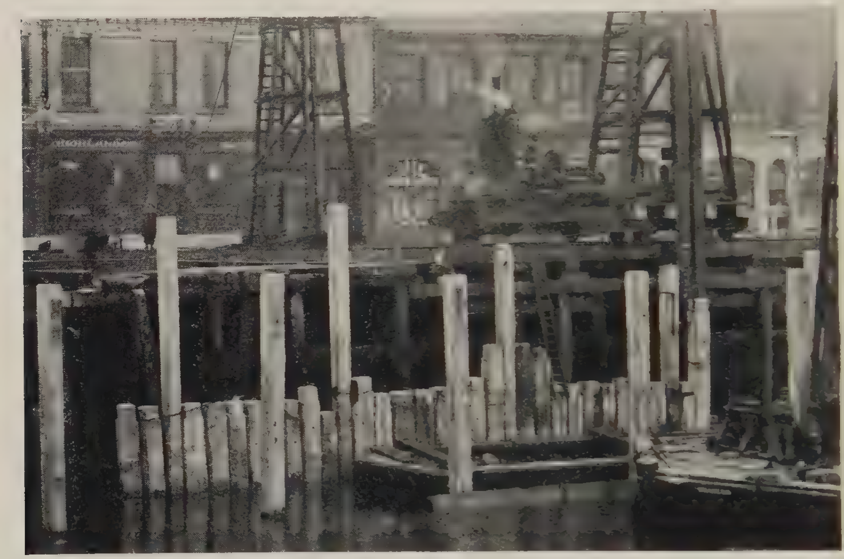


Fig. 142.—Reinforced Concrete Sheet Piling at North Shields.

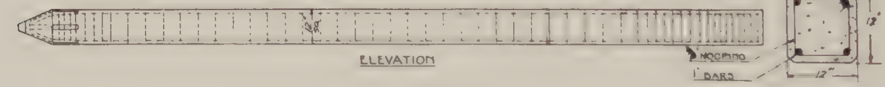


Fig. 143.

Pile-Driving.—Reinforced concrete piles are generally driven with a heavy hammer and a small fall. A semi-automatic hammer giving 40 blows a minute and weighing from $2\frac{1}{2}$ to 5 tons is suitable. It is good practice to use a hammer of greater weight than the pile.

Reinforcement.—Square piles (*Fig.* 143) are generally reinforced with four or eight longitudinal bars bound with $\frac{1}{8}$-in. or $\frac{3}{16}$-in. wire and kept apart by cast-iron spacers. The binding should be closer together at the ends than in the middle of the pile.

Octagonal piles (*Fig.* 144) have eight main bars wound with a helical of steel wire.

Shoes.—Reinforced concrete piles are fitted with cast-steel or wrought-iron shoes with diamond points.

Sheet Piles (*Figs.* 142 and 145) have to resist a lateral load due to the retention of earth or sand filling and must be suitably reinforced. Usual sizes are 12 in. by 6 in. to 20 in. by 8 in. Extra reinforcement for connection of the pile and the anchorage may be left projecting through the pile side-forms and can be bent towards the face of the pile to clear the guides during driving. They are shod with wrought iron and generally the section is tongued and grooved. Such piles are used extensively in the construction of quays alongside rivers, thus avoiding the necessity for expensive temporary cofferdams.

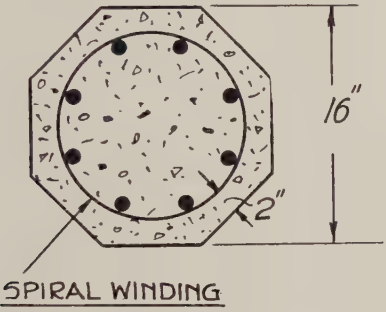


Fig. 144.

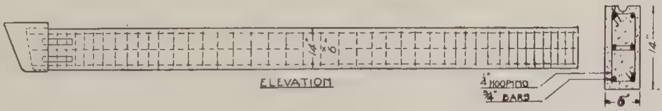


Fig. 145.

***In Situ* Piles.**—Among the methods of casting concrete piles directly in the ground are (1) driving into the ground a double steel shell, the inner one being then collapsed and withdrawn while the outer shell, which is closed at the bottom, is filled with concrete, (2) driving a single steel tube with a steel or concrete point and withdrawing the tube slowly at the same time filling the space left with concrete, and (3) driving a screwed steel tube or mandrel (*Fig.* 146) covered with a pre-cast concrete casing put on in 2-ft. long segments as driving progresses, unscrewing the steel mandrel and filling the pre-cast shell with concrete either plain or reinforced.

Retaining Walls

Design.—A mass of earth standing alone will not remain with vertical faces, but portions will commence to slide down particularly when exposed to rain and frost. The "angle of repose" or the natural angle of slope will vary with different materials and also in the same material according to the state of consolidation and dryness. Dry sand will usually slope at an angle of about 30 degrees with the horizontal, whereas clean firm gravel will make an angle of 45 degrees. Material piled beyond the natural angle must be supported by artificial means, and this support is provided by a retaining wall.

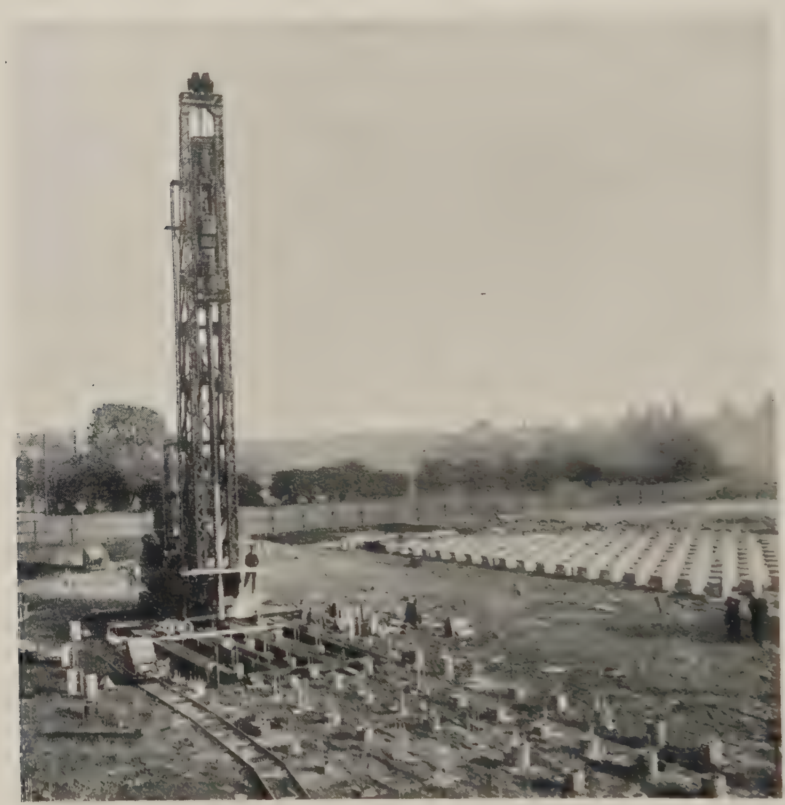


Fig. 146.—Reinforced Concrete "Shell" Piling at Leicester.

The conditions are illustrated in *Fig.* 147, where the natural slope of the soil is indicated by the sloping line *a-b* and the retaining wall is shown in outline above the lower ground level. The sloping line *a-c* denotes the "plane of rupture," and it is only the wedge-shaped portion of earth between this line and the back of the wall which will require to be supported. The removal of the wall would cause this portion only to slip in the first case, because there is a large amount of friction set up by the portion that is tending to slide and the portion which will naturally remain stationary. The earth contained in the triangle between the line *a-c* and the back of the wall shown as *a-d*, presses against the wall and tends to push it over, and the wall must have sufficient weight and strength to resist this tendency. In the calculations it is usual to consider a length of 1 ft. of wall and earth which forms a convenient unit, and it will be clear that if a piece 12 in. long is designed and repeated throughout the length of the wall the whole will be satisfactory. The designer has to consider both the vertical portion of the wall and the base because the latter must be sufficiently large to anchor the vertical portion and distribute the pressure over the area of foundation required to bring the load per square foot within the safe resistance of the soil.

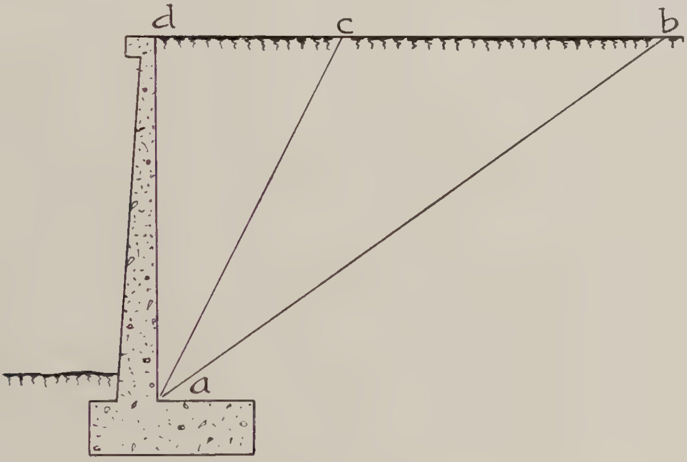


Fig. 147.

In the case of masonry or brick retaining walls the joints of which have an almost negligible tensile strength the resistance to the thrust of the earth is dependent on the thickness and weight of the wall itself, and this must be sufficient to prevent overturning. This means that very thick and heavy walls have to be built, involving large expenditure and frequently loss of space, but in the case of reinforced concrete walls the resistance will be given by the weight of the wall and of the earth overlying the base.

Types of Retaining Walls.—The types of retaining walls in general use number five: (*a*) the unreinforced gravity wall (*Fig.* 148) which depends for its stability against overturning on its own weight ; (*b*) the ell-shaped reinforced concrete wall (*Fig.* 149) with the footing slab entirely behind the wall ; (*c*) the ell-shaped reinforced concrete wall (*Fig.* 149) with the footing slab entirely in front of the wall ; (*d*) the tee-shaped reinforced concrete wall (*Fig.* 150) with the vertical stem placed at some point between the toe and heel of the footing slab ; and (*e*) the basement wall with a cantilever upper slab (*Fig.* 150) for pavement lights or roadway.

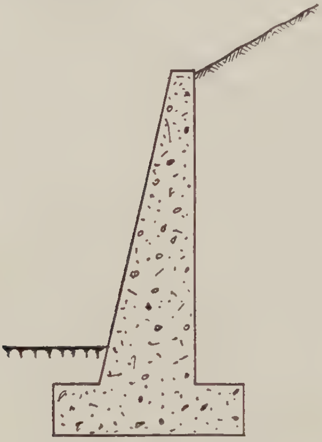


Fig. 148.

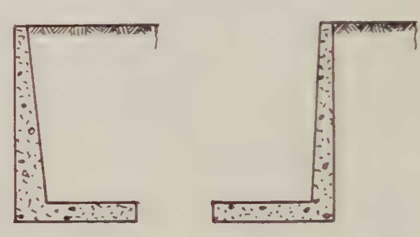


Fig. 149.

The first type is less frequently met with nowadays than formerly since it is relatively more costly to build than the others. It is still used, however, when there is danger of vibration of the ground due to neighbouring moving masses such as reciprocating engines. The second type has a high factor of safety against overturning since the earth behind the wall assists in maintaining its equilibrium. This additional security is absent from type (*c*) which is a common form of construction for basements. The most

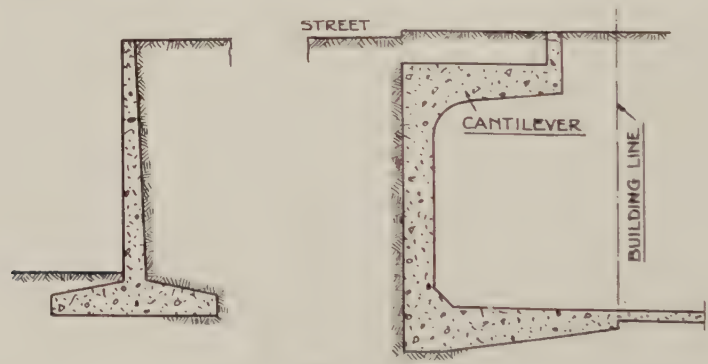


Fig. 150.

usual method of designing a reinforced concrete retaining wall is as shown in type (*d*) *Fig.* 150, but with the projection of the footing slab in front of the face of the vertical wall equal to one-third of the width of the foundation slab. This latter condition ensures a minimum volume of material in the base. The fifth type is rarely met with except in large cities where ground space is valuable.

Types *b*, *c*, *d* and *e* all act as vertical cantilever slabs and therefore the main steel in the wall runs in a vertical direction. Since the bending-moment decreases very rapidly from the bottom upwards very little steel is required near the top of the wall.

If the wall is more than 12 ft. in height it is often economical to insert counterforts on the earth side as shown in *Fig.* 151, at 8-ft. to 10-ft. centres and arrange the steel in the vertical wall so that it spans horizontally.

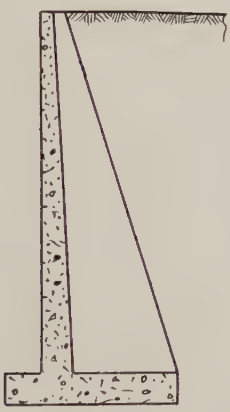


Fig. 151.

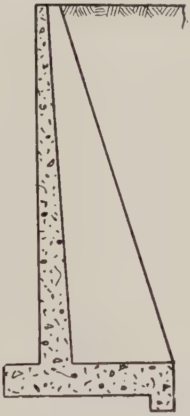


Fig. 152.

In such cases the counterforts must be reinforced to act as wedge-shaped beams by carrying steel up from the base slab along the sloping back of the counterfort. The latter must also be tied into the wall to prevent the wall being pushed away from it by the earth pressure. The bottom slab, behind the vertical wall, is designed to span between the counterforts or, if a beam is inserted (*Fig.* 152) at the back of the slab the latter may be regarded as supported on all four sides.

Provision should be made for contraction joints about every 30 ft. along the wall. These may be filled in with bitumen or patent joint filler. Horizontal steel should not cross these joints.

The foundation slab should never be less than 3 ft. below ground level in front of the wall else its safety may be endangered by the action of frost on the earth.

Formwork.—With cantilever walls there is often a substantial fillet or bracket at the bottom of the back of the wall. The form for this is built as a separate panel with the same spacing of studs as for the wall itself. As there will be upward pressure on this panel it must be well anchored down, generally by wiring to the reinforcing steel. The wall panel is set on top of the sloping panel and the studs of each nailed together. There should be a spacer at the bottom of the wall panel. A 6-in. by 1-in. diagonal brace is nailed from the sloping to the vertical studs to help support and stiffen the wall form. The first pair of walings will be at the junction of the sloping and vertical studs, but if this is more than about 2 ft. high the bottom of the studs must be held by walings bolted through the wall or braced from the outside. As the back of the wall will usually be on a batter the spacers will vary in length. The top and bottom spacers must be cut to the exact width of the wall and are set before the others. The intermediate spacers are cut approximately to suit the width and are wedged into the forms to hold the panels to line.

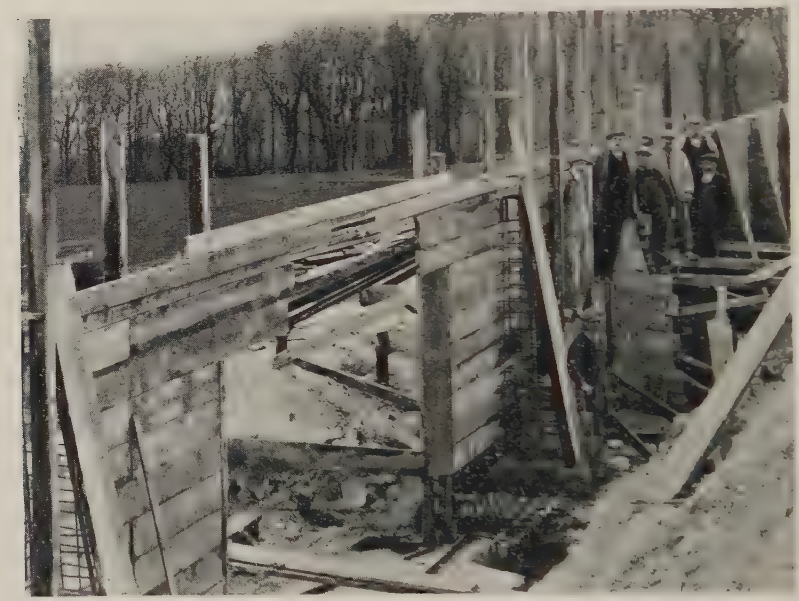


Fig. 153.—Forms for Retaining Wall.

Shuttering for counterfort walls (*Fig.* 153) presents no particular difficulty. The sloping back of the counterfort is built similarly to a bulkhead. For easy stripping it should be built as a panel with 4-in. by 1-in. battens down the centre and only lightly nailed to the stop battens on the sides as the pressure of the concrete will keep it in place. The sheeting of the sides of the counterforts should not be cut to the slope, but should be of random lengths to save material. Since counterforts are usually about 8 ft. apart they are easily braced against each other with diagonal braces butting against a stop block nailed to a 2-in. board or a 4-in. by 4-in. scantling which holds the lowest waling. When the counterforts are short it is usually better to run the sheeting vertically. The braces should not be horizontal between counterforts unless the concrete is brought up in each one at the same rate. As the counterforts will be stripped first their sheeting should overlap the wall sheeting.

Curved Walls.—These will have vertical sheeting and horizontal yokes. The curve should be laid out on the ground by driving in a peg at the centre, and marking out the radii with a lath nailed to the peg and with a hole at the other end for a pencil. Along the lath are measured the outside radius plus the sheeting thickness and the inside radius less the sheeting thickness. Along the circumference are loosely placed 2-in. boards of a width depending on the radius, and lapping 6 in. to 12 in. The lath is swung round over the boards, which are adjusted until the laps are about equal, and the depth of cut at the ends the same, when they are nailed lightly together and the curve marked out on them. They are then taken apart and the curves cut out. When put together again with the same amount of lap they will give the correct radius. When possible it will save timber to cut both inside and outside yokes from the same board and to do this it will pay to use wider and shorter boards. The inside yokes should be marked out first and then the planks taken apart and moved farther out until the greater outside curve coincides with the inner curve at the centre of the yokes. The

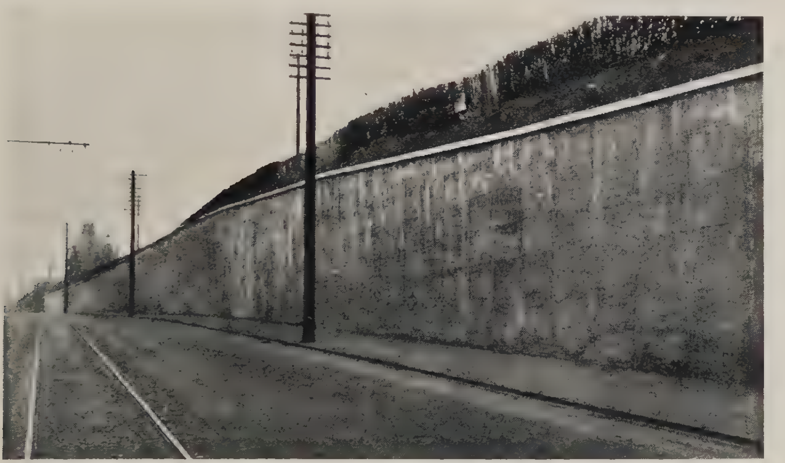


Fig. 154.—Reinforced Concrete Retaining Wall at Derby.

outside yokes must be longer than the inside yokes because of the greater curvature if each is lapped the same amount, the ratio of the lengths being approximately the same as the ratio of the outside and inside radii. The inside yokes should be cut back at each end to avoid feather edges. Sometimes only one plank is marked out in this way and used as a template for cutting the others, but if there is a slight error in the template this will be repeated in all the yokes and they may not fit together so well.

Instead of using 2-in. boards two thicknesses of 1-in. boards can be used nailed together with the end of one board at the centre of the other. This is more suitable for inside than outside yokes. The least depth of outside yoke at the centre should be not less than 4 in., nor should the end depth of the inside yokes be less than 4 in. at the centre of the lap. When the yokes are cut out they are nailed together at the laps, the radius being checked again before driving home the nails. The sheeting is nailed on either in place or in panel form. The sharper the curve the narrower must be the sheeting. The spacing of the yokes depends on the allowable span of the sheeting. When erected the forms are wired across at the laps of

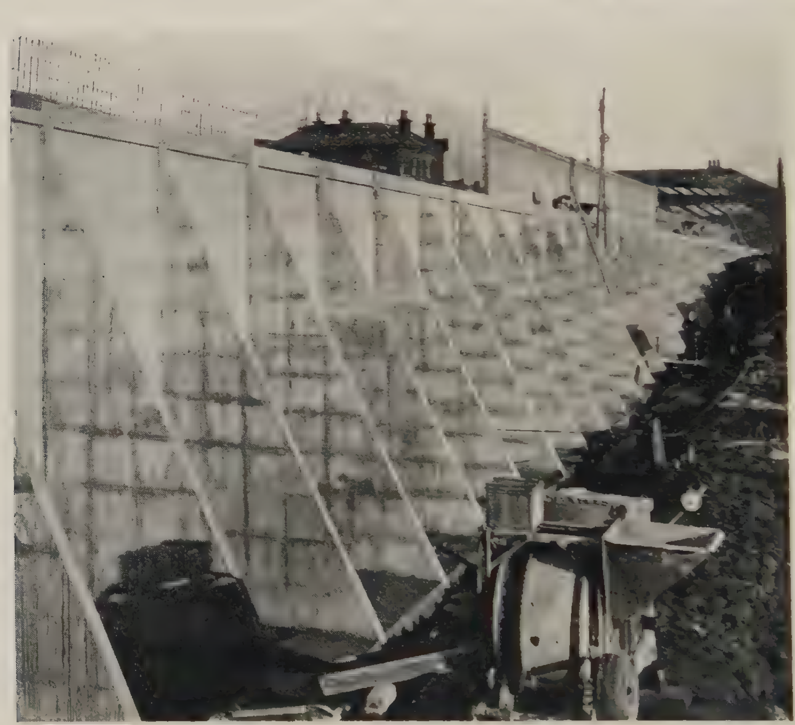


Fig. 155.—Reinforced Concrete Retaining Wall at Preston.

the yokes and at intermediate points so that the wires are not over 30 in. apart, depending on the height of the wall. If the wall is high vertical walings should be used at the ties to stiffen the form. With very flat curves it is often possible to spring the boards horizontally to the curvature. In this case the lowest board is staked to line and the studs then nailed on.

If a wall is a complete circle, as in tanks and silos, and often in small foundations, it is possible to dispense with the ties, but in this case the timber of the outside yokes is in tension and the nails or bolts at the lap of the yokes in shear. Since it takes about ten 20*d*. spikes to equal one $\frac{5}{8}$-in. bolt in shear bolts should be employed to fasten the yokes together using at least two to a joint. If the wall is very low and of small diameter five 20*d*. spikes can be used at each joint instead of bolts. Concreting must be brought up equally around the wall otherwise the forms will be thrown out of shape.

Concreting.—The method to be used will depend on whether filling is in position behind the wall or not. In the latter case a working platform approached by a ramp may be constructed of 9-in. by 3-in. timber decking supported by transoms bolted to the studs. In this case the studs must be of at least 6-in. by 3-in. timber. Where the wall is to be surcharged the concrete may be transported in skips running on jubilee track at the top of the slope and discharged into timber chutes leading to the formwork. For high walls the concrete is often hoisted by travelling cranes and dumped on a working platform before filling the forms.

Walls

Formwork.—The method used for making and erecting wall forms will depend on the size of the job. For small basements it is best to construct forms to cover the whole area while larger jobs require panel construction. It is always well to build sufficient forms for one full day's concreting, say, from 40 cu. yds. up depending upon the size of the mixer. If a wall can be poured in 7 hours there will be at least 1 hour each day left, most of which time will be wasted as the last hour cannot be used efficiently.

If the form is to be built in place, which is the cheapest method for small walls, it should be built as lightly as possible, consistent with strength. The number of nails used should be kept down to a minimum, just sufficient to keep the different members of the forms in place. Nails are seldom used for strength, and they increase the cost of stripping and lessen the salvage value of the timber.

Walls from 8 ft. to 12 ft. high require 4-in. by 2-in. studs at 14-in. to 16-in. centres when 1-in. sheeting is used. Studs need not be cut off at the top of the wall but can be used in random lengths to avoid waste. In all form building an inexperienced man may spend a lot of money cutting up material to exact lengths and producing neat but wasteful forms.

In erection of forms the studs are first set to line all the way through

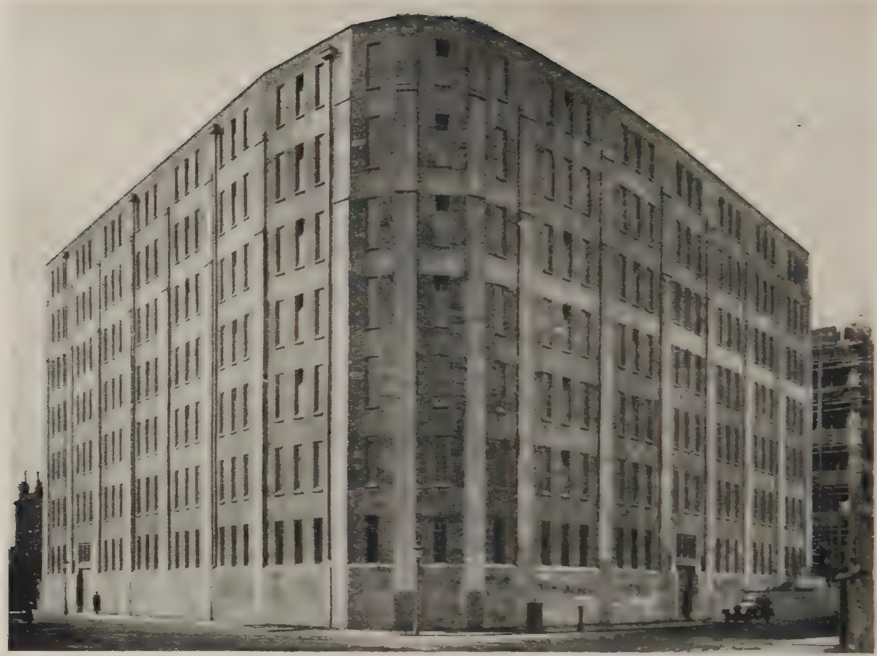


Fig. 156.—Reinforced Concrete Tobacco Warehouse.

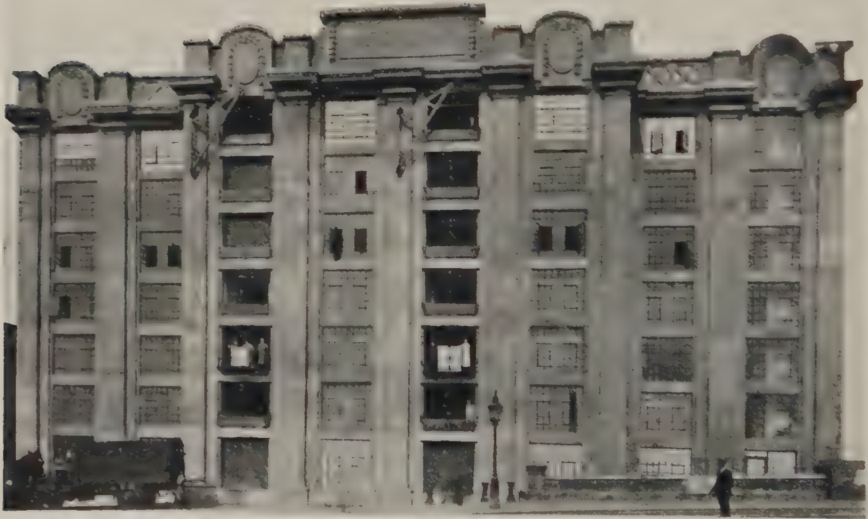


Fig. 157.—Reinforced Concrete Warehouse at Blackfriars.

with a board nailed on top and bottom to hold them together, and temporarily braced with 6-in. by 1-in. boards. Lines should always be set an inch or two away from the actual face of the wall so that the forms will not interfere with them. The lowest board should be nailed on level, otherwise the sheeting will tend to run up or down hill, and if the foundation is stepped or uneven the special widths of boards are put on last, not first. The sheeting is nailed on lightly, breaking joints preferably at the studs and the tongue tapped well into the groove so as to get a tight form.

Fig. 158.—Reinforced Concrete Factory in London.

If the wall is narrow and there is much reinforcing steel to place, one side should be completed first, plumbed and braced, and the other side set from this by means of 2-in. by 1-in. spacers cut to the exact width of the wall. The spacers should be about 3 ft. apart vertically and at alternate rows of studs, and are knocked out as the concrete reaches them. If the wall is wide enough for a man to work inside to place the steel both sides may be brought up together and less temporary bracing will be required since the studs can be tied across at the top with short pieces of board.

Only one side of a wall should be accurately set to line, plumbed, and braced, since the other side will be set automatically by the spacers. The side to set first depends usually on which is the most important face of the wall, generally the outside if exposed to view and the inside if below ground, also ease of bracing enters into consideration. A good deal of time can be wasted in trying to set and plumb each side independently.

When the form is completed the temporary braces should be replaced by 4-in. by 2-in. or 4½-in. by 3-in. braces, as in *Fig.* 160, about 10 ft. apart, the distance depending mainly on how stiff the forms are built. If the wall is low, 6-in. by 1-in. braces will be sufficient, as in *Fig.* 161. Low and unimportant walls can be built without walings, but with heights greater than 6 ft. there is always danger of the form twisting and getting out of line from the impact of the concrete if walings are not used. Walings will transfer the pressure from one stud to another if a tie is loose or breaks. Walings should only be nailed on sufficiently to remain in place. If they are used it is possible with care to do without exterior braces, even with very high walls, but a few are always advisable. The braces should be wedged against the walings, and are very useful if the form begins to get out of line since the wedges can be loosened or tightened to bring the form to line again.

Fig. 159.—Reinforced Concrete Pavilion at Norwich.

The ties can be inserted before plumbing the forms but should not be tightened up until afterwards; if this is done beforehand some will become slack and others too tight and they will have to be readjusted.

Ties.—If wire ties are used they should be twisted up tight with the claw end of a hammer, but not so tight that they are on the verge of breaking, and there should be a spacer just above each wire to draw the forms up against. The spacers should be above the wires, as they are commonly used for walking on and placing them above prevents walking on the wires. The wires should be hammered flat against the walings or studs, before tightening up, or wedges may be driven in after tightening, otherwise the slack will be taken up under pressure and the form will give slightly. Two men should work together on the wires, one each side of the wall.

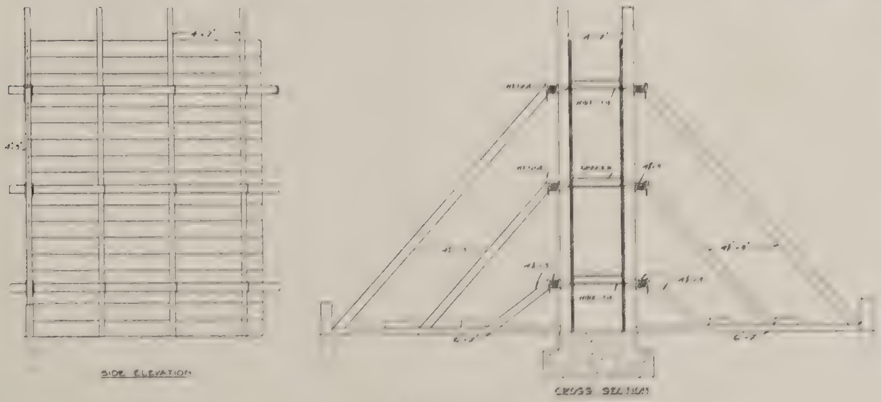

SIDE ELEVATION
CROSS SECTION
6'-7"
6'-7"

Fig. 160.

Bolts are not used with single studs without walings, but if a stud is made up of two pieces the bolt is placed between them, bearing on a short piece of timber. When walings are used the bolt is placed through the waling only, close to the stud, to save boring through the stud.

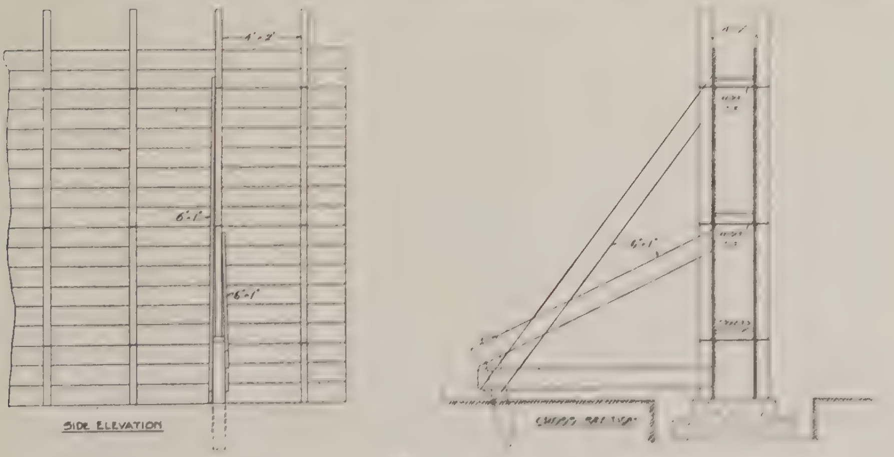

4'-2"
6'-1"
6'-1"
6'-1"
SIDE ELEVATION
CROSS SECTION

Fig. 161.

If a contractor is doing a great deal of concrete work he will generally find plain round rods and patent clamps more economical than bolts, since a smaller size can be used in the first place and they can be ordered long enough so that they can be used many times over in walls or columns.

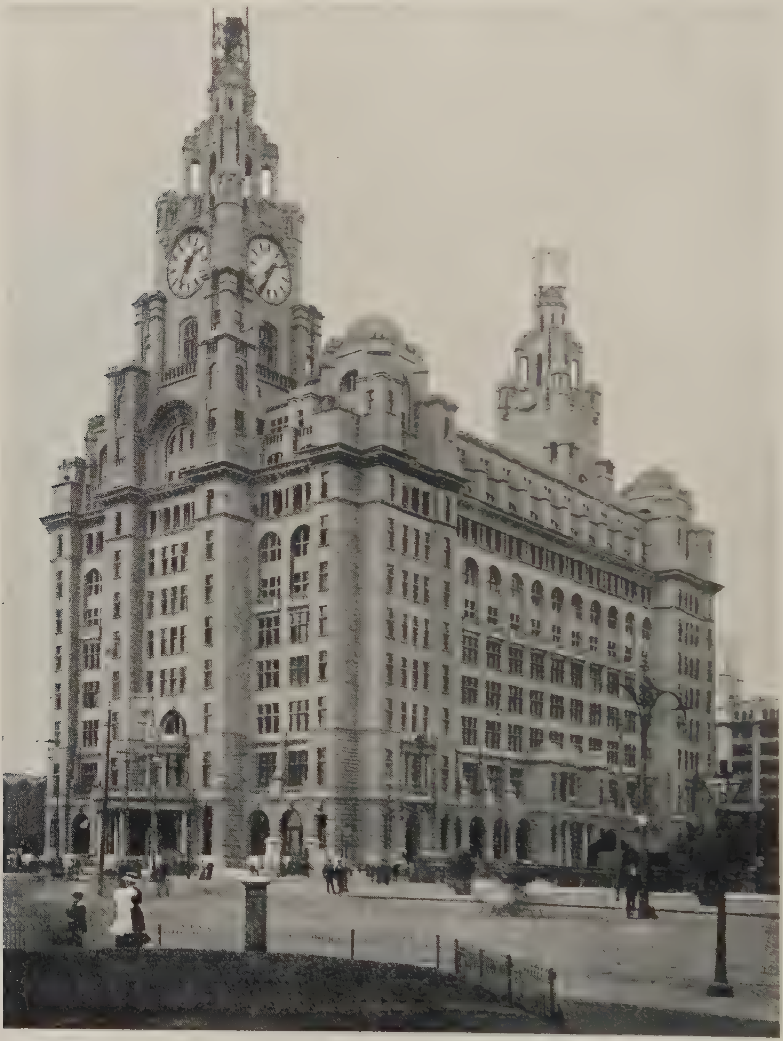


Fig. 162.—Royal Liver Building, Liverpool: A Tall Reinforced Concrete Frame Building.

They are more easily drawn than bolts, and if they have to be left in the wall the loss is less. Bolts, to be adaptable, must have long threads, because of the different thicknesses of wall, or else several lengths must be kept in stock, while rods 3 ft. or 4 ft. long can be used almost anywhere. The initial cost of clamps, however, does not warrant their use unless they can be used several times over.

Panel Forms.—On a large job where wall forms can be used several times over it will be best to build them in panels. This has also the advantage that the panels can be made up in advance, so saving time in erection. Their size will depend on the facilities for handling them ; 10 ft. by 8 ft. is a convenient size, weighing about 550 lbs., and can be handled by four to six men.

Walings are generally put on during erection and the holes bored at that time, and the walings should be long enough to overlap the end stud of the adjoining panel. The ends of the sheeting must, of course, be cut off square ; at one end of the panel there will be no stud, and at the other end the sheeting will finish at the centre of the stud, so that the next panel can join on to the same stud. One side of the wall will be set to line first, plumbed, and braced. The spacers will be lightly tacked on to this form and the other side up-ended against the spacers, bolts or wires being inserted and drawn up tight against the spacers.

Fig. 163.—A Reinforced Concrete " Daylight " Factory at Leicester.

As these forms will have to withstand much more handling than when built in place, $1\frac{1}{4}$-in. sheeting and 3-in. or 4-in. by 4-in. studs are better than the lighter sizes. The studs in panel construction should preferably be of the same length as the height of the panel. Wall panels can sometimes be used again in the floor construction, and can be built in the first place with that in mind. The panels should be oiled before being erected.

Single Wall Forms.—A wall poured against an existing wall or against the side of an excavation needs only one form, and this must be braced externally. If there is anything close to brace to horizontal braces are best, but usually they have to be taken diagonally down to the ground where they are held by pegs. In order to be able to adjust and plumb the form, wedges are used between the brace and walings, a nail being driven through both to prevent slipping. If there are any signs of the wall going out

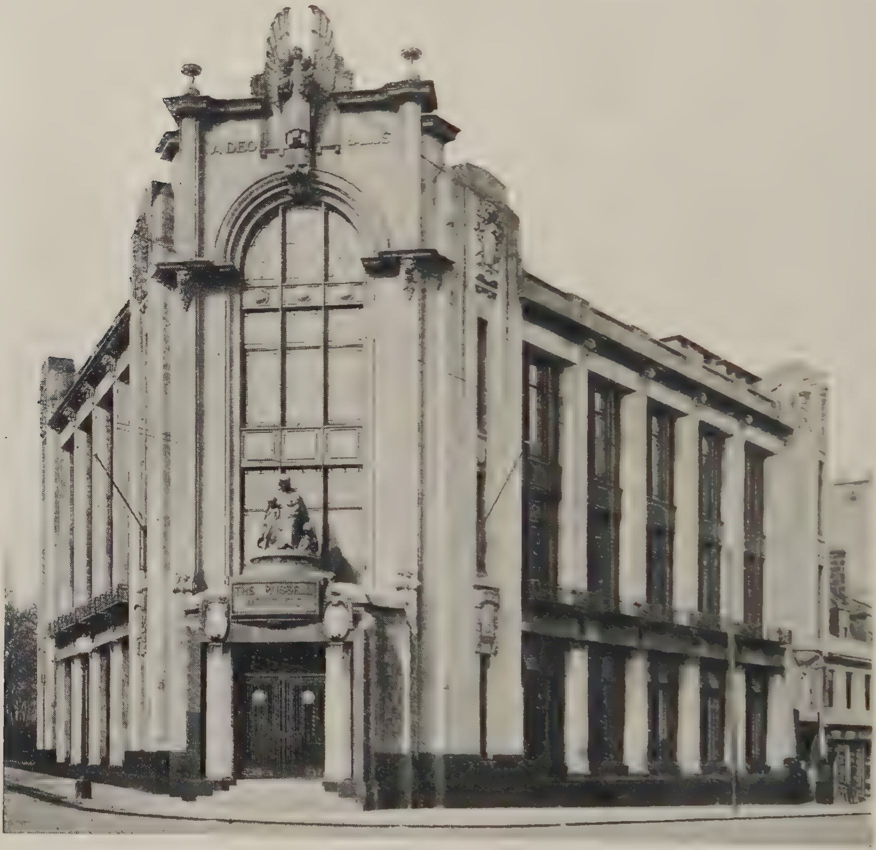


Fig. 164.—The Russell Institute, Paisley: A Reinforced Concrete Frame Building.

of plumb the nails are withdrawn, the wedge driven up, and the nails replaced.

Fig. 165.—Reinforced Concrete Stove and Meter Works at Fulham.

Fig. 166.—Reinforced Concrete Motor Works at Dumfries.

If no walings are used, 6-in. by 1-in. for low walls and 4-in. by 2-in. for high walls are used as braces at each stud and are nailed to stakes. With walings the braces are generally 3 in. or 4 in. by 4 in. and they can take bearing on a 2 in. board or 4-in. by 4-in. timber laid on the ground with a peg at the end. If it is necessary to brace to a finished floor the 4-in. by 4-in. can be held with bolts as for columns.

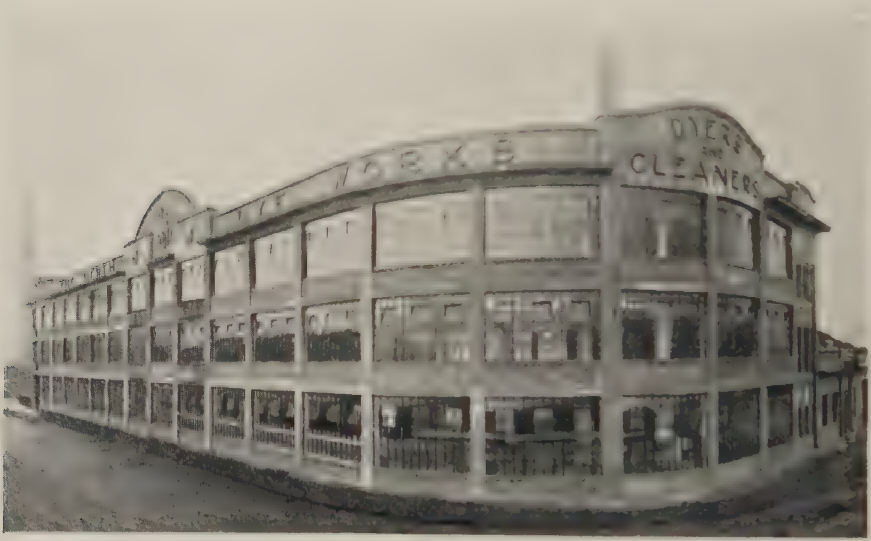


Fig. 167.—Reinforced Concrete Frame Building at Perth.

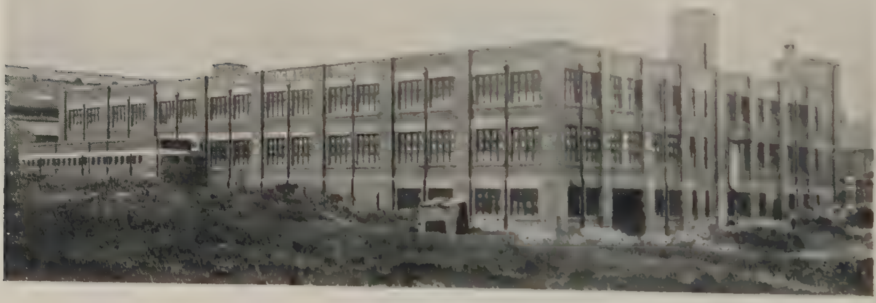


Fig. 168.—Reinforced Concrete Frame Printing Works at Newcastle-on-Tyne.

Concreting.—On large contracts the presence of a chuting plant simplifies the distribution of the concrete but on small jobs placing is usually carried out by means of barrows, concrete carts or jubilee skips discharging either

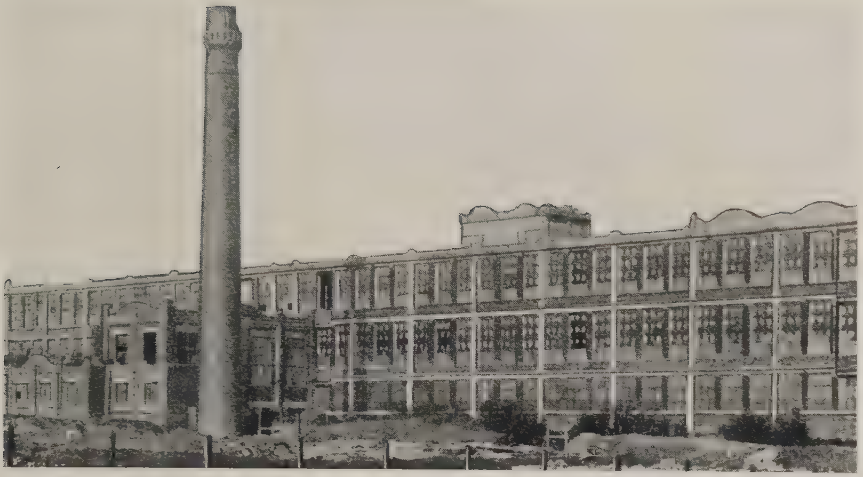


Fig. 169.—Reinforced Concrete Mill, 410 ft. by 85 ft., near Wakefield.

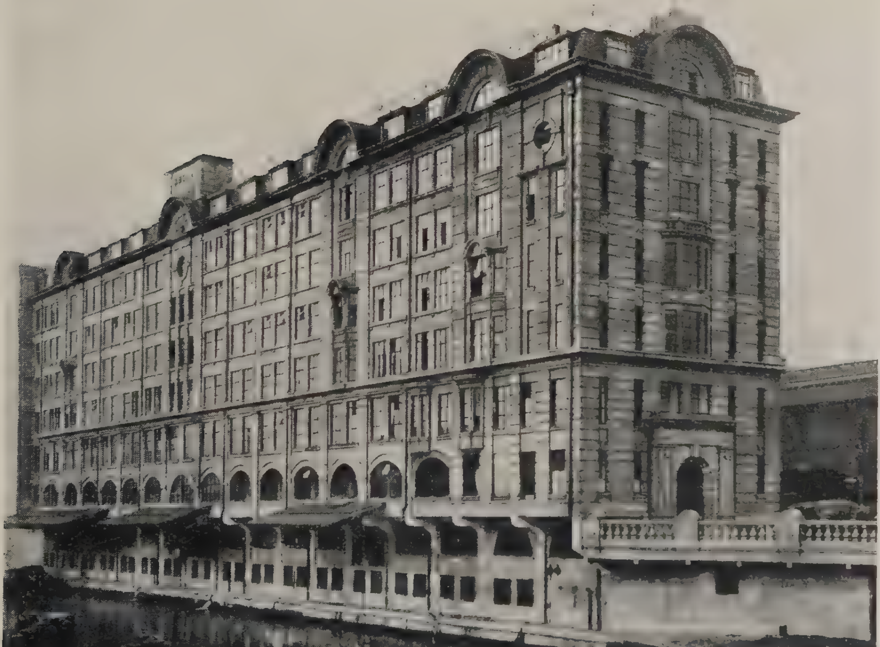


Fig. 170.—Reinforced Concrete Warehouse at Salford.

directly into the forms or into a timber chute with a hopper head at ground level. It is important to inspect the forms before any concrete is poured to ensure that they are free from foreign matter such as shavings or soil. Where only one face of the wall is shuttered it is not unusual to find that some clay has slipped down into the bottom of the forms. This, if not removed, would prevent the formation of a good joint between the wall and the floor slab. Concreting is usually executed in 3 ft. lifts unless the forms are specially designed to be poured the full height. To ensure a good

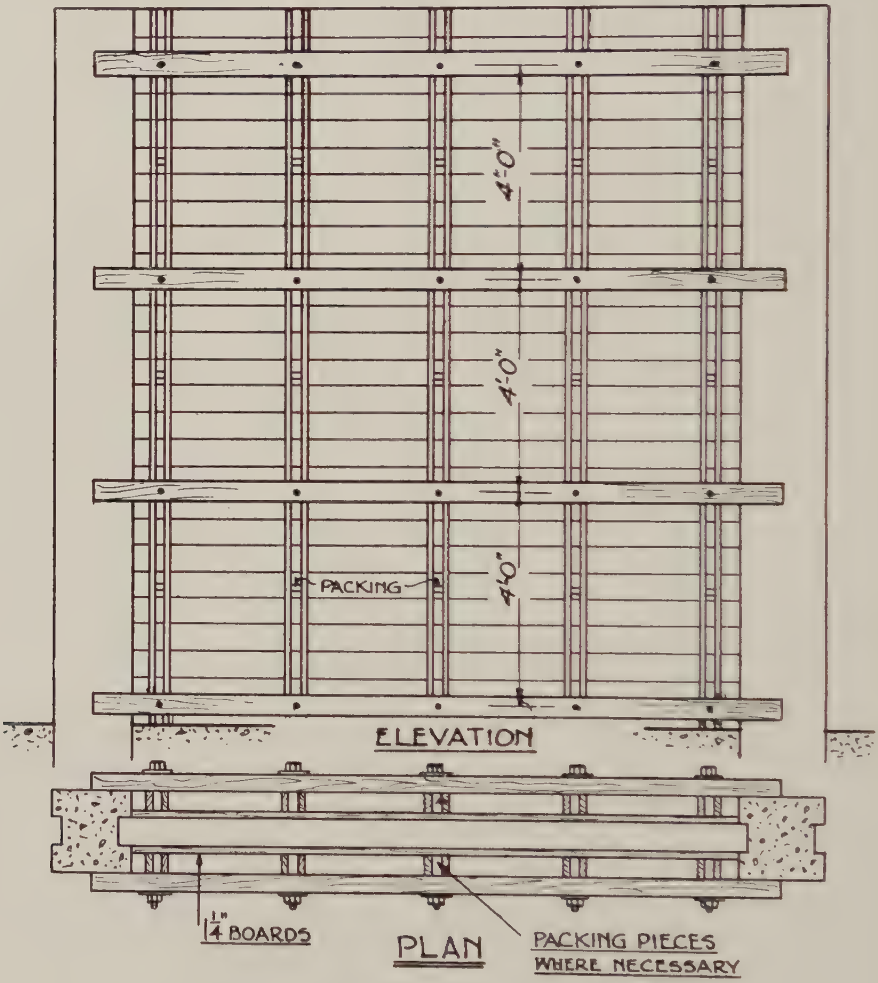

4'-0"
4'-0"
4'-0"
PACKING
ELEVATION
1¼" BOARDS
PLAN
PACKING PIECES WHERE NECESSARY

Fig. 171.

junction between wall and foundation the concrete of the latter should be roughened to remove laitance and wetted before casting the walls.

Reinforcement.—The amount of reinforcement and its position in the wall will depend on the height of the wall, the nature of the soil to be retained and the ratio of the height of the wall to its length. As a general rule it may be stated that the greater amount of reinforcement is required in the shorter direction of the slab. Vertical bars should be arranged to lap over bars protruding from the base so as to give a good bond between the wall and foundation.

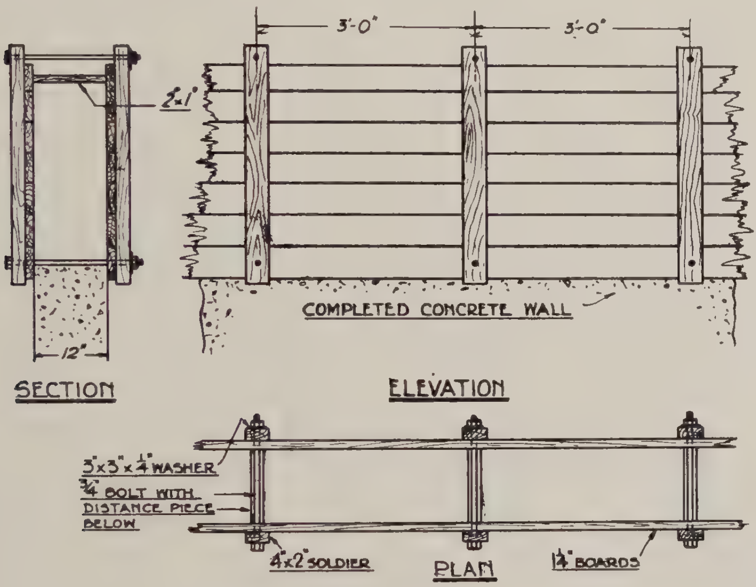


Fig. 172.

Framed Structures

In buildings of the frame type the external walls are often constructed of reinforced concrete panels with a light mesh of steel. Such walls do not carry any vertical load. They are generally designed as supported on four sides if the panels are approximately square, and are seldom made less than 6 in. in thickness in order to facilitate the fixing of steel sashes. Walls of less thickness than 6 in. are also somewhat difficult to pour and tamp properly, especially if the steel is in the form of close meshes.

In many buildings the columns have been recessed so as to provide a groove into which the panel wall fits and thus obtain a rigid connection between the walls and columns. Shuttering for this type of wall often takes the form of horizontal sheeting with double " soldiers " on both sides of the wall (*Fig.* 171). The pairs of " soldiers " are kept apart by wooden distance pieces and transmit the lateral pressure due to the concrete to the walings which are connected together through the wall by $\frac{3}{4}$-in. bolts passing between the double soldiers. The bolts should be wrapped in paper or well greased so they may be drawn easily.

Forms for heavier solid walls are often constructed in cleated panels (*Fig.* 172) 3 ft. high and 10 to 12 ft. long, the two sides being bolted together and separated by distance pieces.

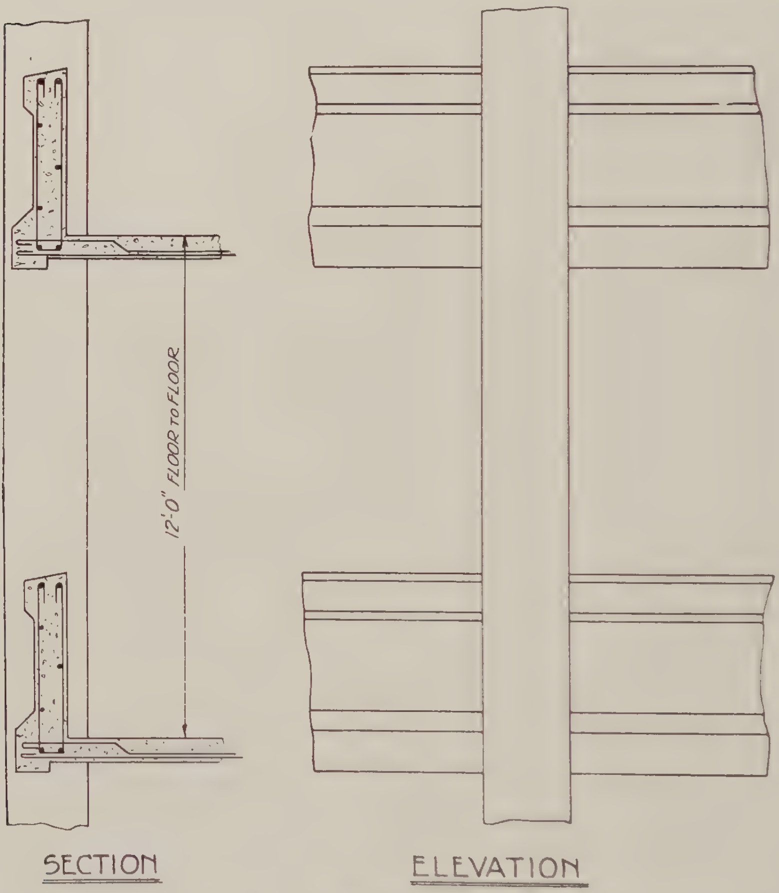


Fig. 173.

The surface treatment of this class of wall follows the practice laid down in Part III.

In factory buildings where the maximum possible lighting is requisite, the spaces between the columns of the frame building are filled in with steel sashes except for a low spandrel wall reaching to a height of 2 ft. or so above the level of the floors and acting as a support to the edge of the slab to transmit its load to the columns (*Fig.* 173). These spandrel beams seldom require much longitudinal reinforcement since their depth is generally very much greater than the effective depth required to resist the bending moment acting on them.

Panelling.—Omitting such structures as that shown in *Fig.* 174, in which no walling is necessary, the architect has a large choice of methods for filling in the spaces between columns and beams.

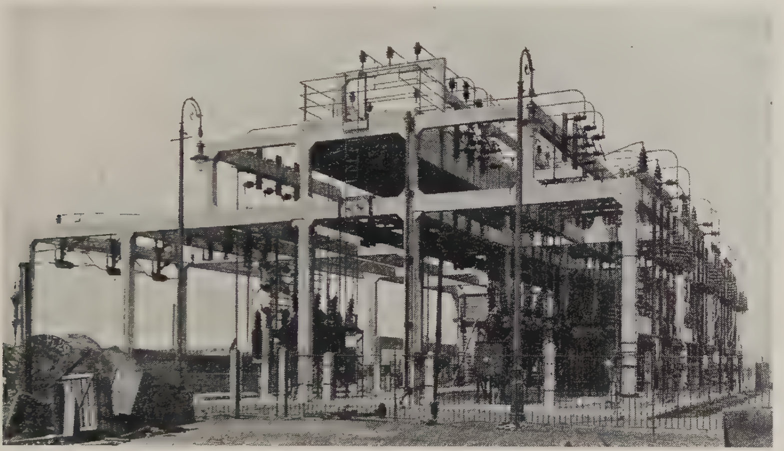


Fig. 174.—Reinforced Concrete Framework and Platform for Outdoor Switchgear.

WALLS AND PARTITIONS

	Weight in lbs. per sq. ft. of vertical wall.
Brickwork	10 lbs. per 1 in. thickness.
Breeze partitions	8 ,, ,, ,, ,,
Plaster (each face)	9 ,, ,, ,, ,,
Light timber-studded partitions complete .	10 to 18 lbs. per sq. ft.
Concrete walls	12 lbs. per 1 in. thickness.
Windows :	
Glass	14 ,, ,, ,, ,,
Glazing bars	3–6 lbs. per sq. ft.

Floors

Ground floors may be divided into two classes, (*a*) those on firm solid ground and requiring very little reinforcement except where there is a possibility of the existence of weak-bearing patches ; and (*b*) floors supported on columns and footings or on piles. The latter class is designed on similar lines to upper floors and need not be further considered at this stage. Ground floors are sometimes left with a screeded and floated surface or a wearing course of granite chippings and cement in the proportions of 2 to 1 and not less than $\frac{3}{4}$ in. thick if laid before the main slab has hardened or than 1 in. if placed on top of the already hardened slab. The former method is cheaper and there is no question whether the finish adheres to the slab below, but the latter method has some disadvantages and if applied too late the results may be serious. Such floors are easily cleansed and very durable under hard wear. An improvement to this type of floor may be made by rubbing it with carborundum and sand, using plenty of water, after it has been cured for about ten days.

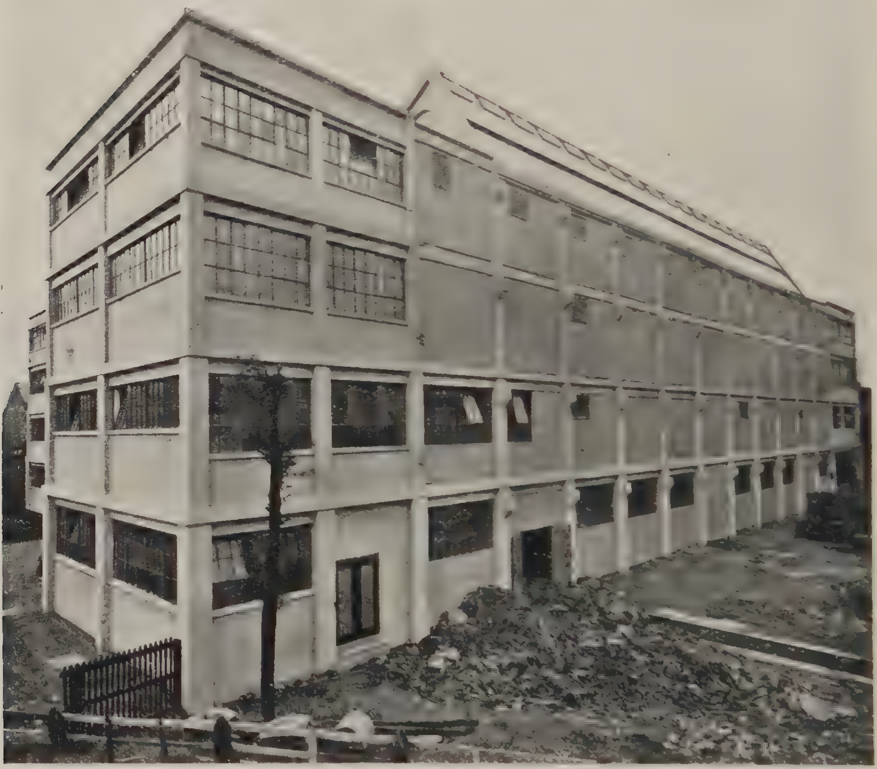


Fig. 175.—Warehouse at Staines.

Where a wood surface is desired, 3-in. by 2-in. or 4-in. by 2-in. creosoted screeds of timber are set in the floor slab (*Fig.* 177), and the flooring boards nailed down to these. The boards are generally of hardwood, 1 in. in thickness, and the spaces between boards and screeds are sometimes filled in with breeze concrete mixed in the proportions of 1 : 3 : 6.

Fig. 176.—New Repair Shop at Cricklewood.

Another type of floor consists of 4-in. by 4-in. timbers spaced at 2 ft. centres and bedded in 6-in. thickness of breeze on top of the concrete slab.

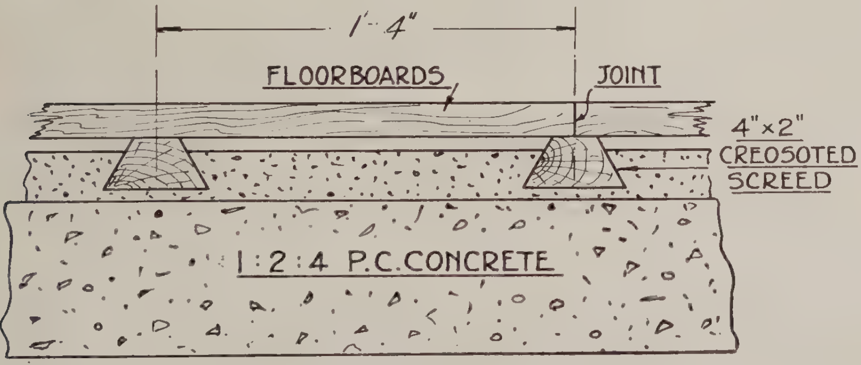


Fig. 177.

2-in. boards are nailed across the sleepers and directly over these there is a wearing surface of 6-in. by 2-in. tongued and grooved flooring (*Fig.* 178). Creosoted wood block flooring resting on 4 in. to 6 in. of 1 : 3 : 6

concrete the top surface of which has been tarred is also occasionally used (*Fig.* 179).

Concreting Ground Floors.—Except in very large buildings the ground floors are usually concreted without the use of a chuting plant. As soon as the reinforcement is in position and has been inspected and passed by the clerk of works runways supported on low horses may be erected in convenient directions and the concrete conveyed over these in either barrows or concrete carts. As it will seldom be possible to adopt continuous pouring of the concrete, care must be exercised to arrange that the construction joints shall be straight in line by the use of stop boards or other devices running in a direction at right angles to that of the main reinforcing bars.

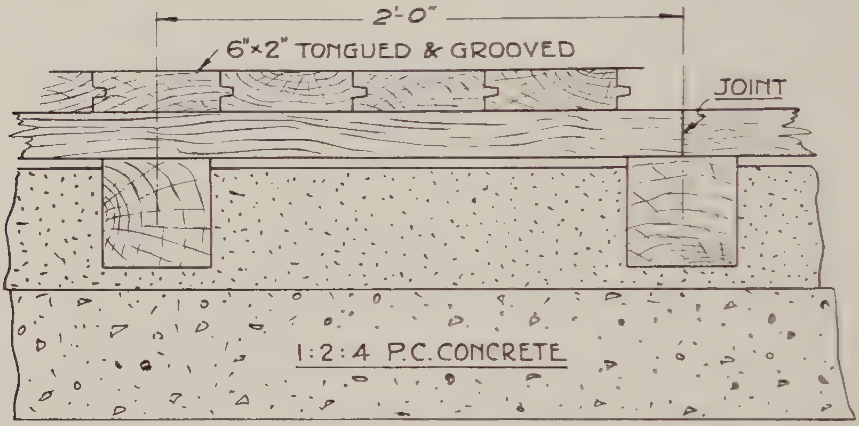


Fig. 178.

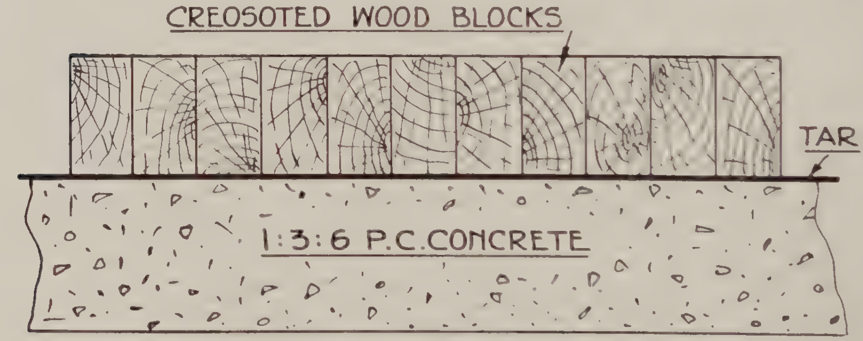


Fig. 179.

Tamping must be thoroughly executed else there is a possibility of the occurrence of air-pockets around the steel.

Wherever new concrete is to be bonded to that which has partly hardened the joint must be properly madeas already described.

The types of upper floor in common use are : (1) beam and slab, (2) flat slab, (3) hollow-tile and (4) pre-cast beams. The selection of a type depends on the superimposed load and the spacing of the columns. The first two are almost equal in economy for a building containing columns at equal spacing in both directions, but if there is a considerable number of stories the flat-slab floor (*Fig.* 180) owing to its adaptability for low headroom is generally cheaper. Both of these types can be constructed for extremely heavy loads of a uniformly distributed nature, but where heavily-concentrated loads are to be carried or large openings are necessary the beam and slab form (*Fig.* 181) is preferable.

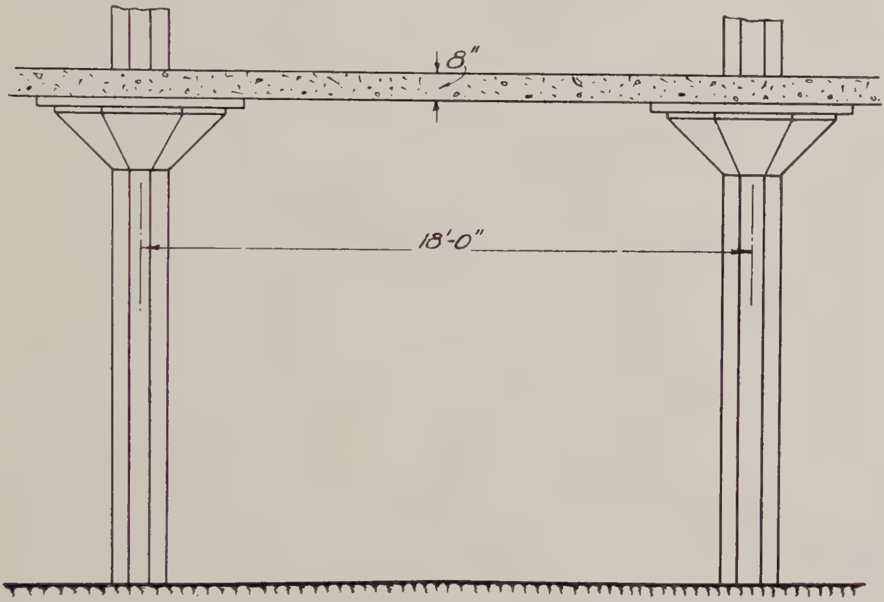


Fig. 180.

The hollow-tile floor (*Fig.* 182) is especially suitable where light loads are to be carried over long spans, the tile being much lighter than the concrete for which it is substituted. Like the flat slab floor it has the advantage of giving a flat ceiling.

Over cartway areas and in similar situations where long span beams are required a lattice girder (*Fig.* 183) is very much lighter in weight than a solid rib and is often more economical notwithstanding the extra form-work necessary in its construction.

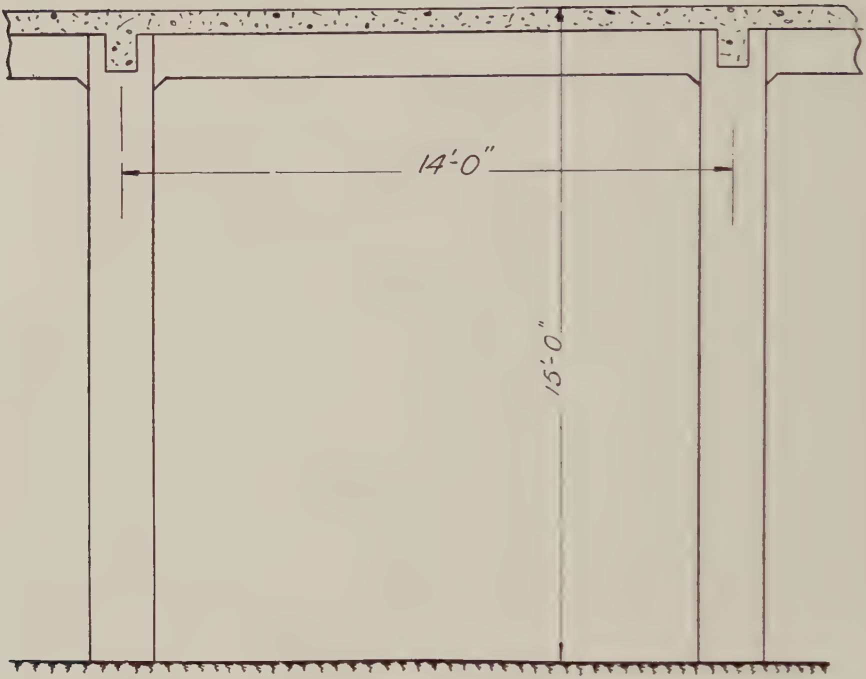


Fig. 181.

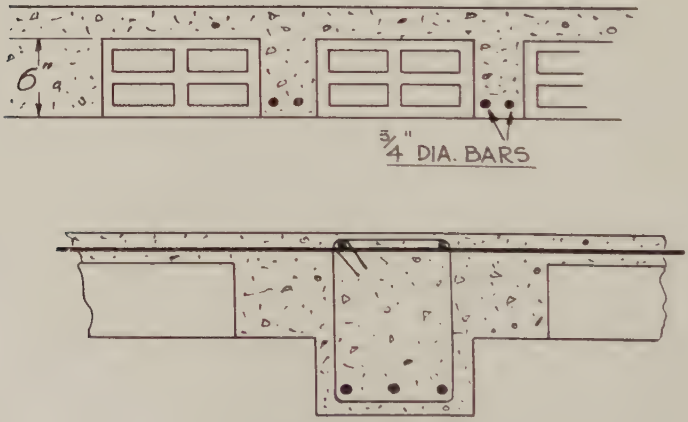

6"
3/4" DIA. BARS

Fig. 182.

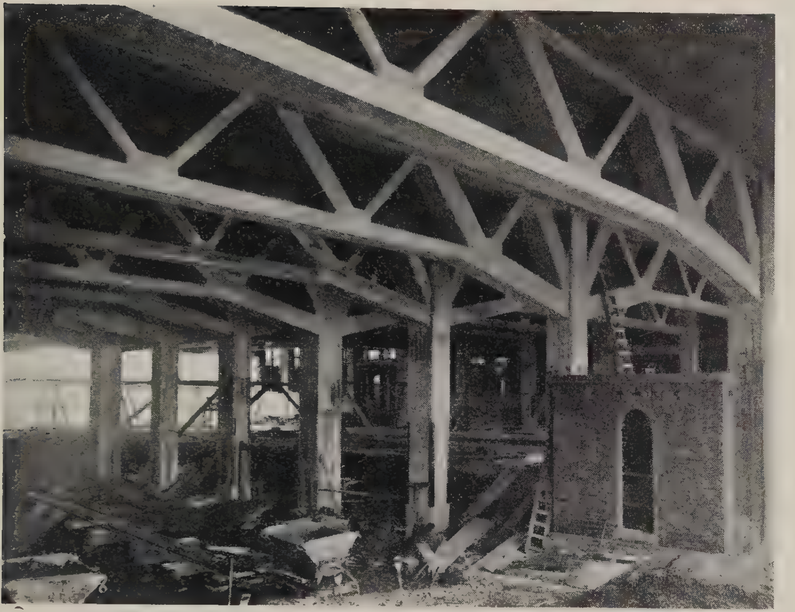


Fig. 183.—Reinforced Concrete Beams, Warren Girder Type, span 50 ft., at Royal Albert Docks.

Superimposed or Live Loads, excluding the Dead Weight of the Floor

Description or Purpose.	Equivalent Dead Load in lbs. per sq. ft.
Domestic buildings and private houses	70
Hospitals, hotels, and similar buildings	84
Offices	100
Public buildings, schools, assembly halls, theatres, retail shops, workshops	112
Drill and ball rooms or floors subject to similar vibration	150
Warehouses, book stores, etc.	Not less than 224
Floors to carry machinery, printing presses, flour, paper, water tanks, etc.	Up to ½ ton, but each case must be investigated
Garages for light and private cars	Point load from axle loads up to 2 tons
Heavy lorries and tractors	Up to 11-ton wheel loads

Dead or Structure Loads additional to above

Description.	Weight in lbs. per sq. ft. of surface.
Concrete floor, reinforced concrete floor, granolithic and asphalte	12 lbs. per inch of thickness.
Breeze concrete	7½ ,, ,, ,,
Timber wearing surfaces	4–6 ,, ,, ,,
Nailing strips	2 ,, ,, ,,
Plaster ceiling	10 ,, ,, ,,
Timber floor for domestic buildings (boards and timber joists)	10 ,, ,, ,,

In beam and slab construction the slab should be spanned to its maximum amount and be reinforced to take up the negative bending moments over the supporting ribs as well as the positive moments at mid span. Shear is generally of minor importance in slabs. The ribs, forming tee-beams with the slab, are often designed with a depth below the slab of 1 inch per ft. of span. By suitable arrangement of the lay-out of main and secondary beams economy may sometimes be effected, but it must not be forgotten that although close spacing of beams results in a thinner slab being required it also increases the amount of formwork necessary. If the foundations require to be piled it often pays to increase the column spacing and use as few as possible large size piles since the actual pitching and driving of the piles is often the most expensive part of such foundations once the pile frame has been brought on the site.

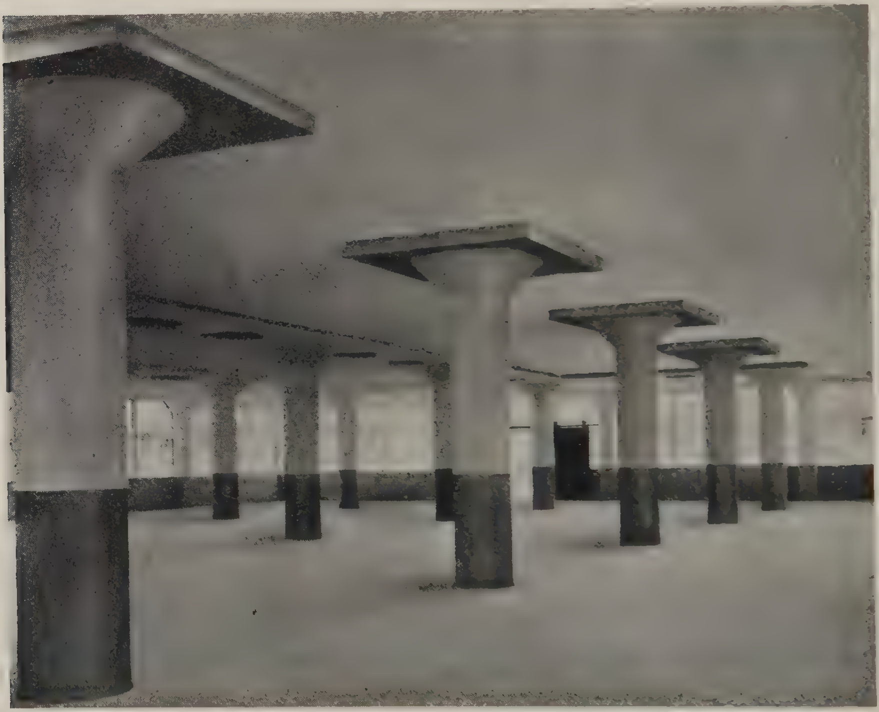


Fig. 184. "Flat Slab" Construction at Melksham (25-ft. Spans to carry 2½ cwts. per sq. ft. super load).

Flat slab floors—for which there are no standard regulations in Great Britain—may be designed either with or without drop panels and reinforced in either two or four directions, the former being preferred in

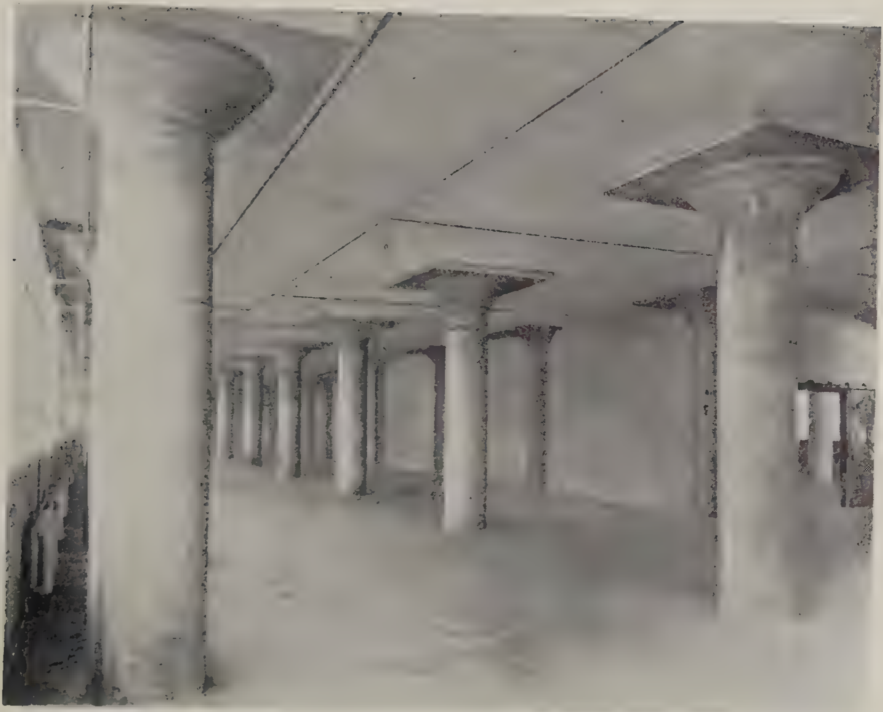


Fig. 185.—" Flat-Slab " Construction at a Factory at Wembley.

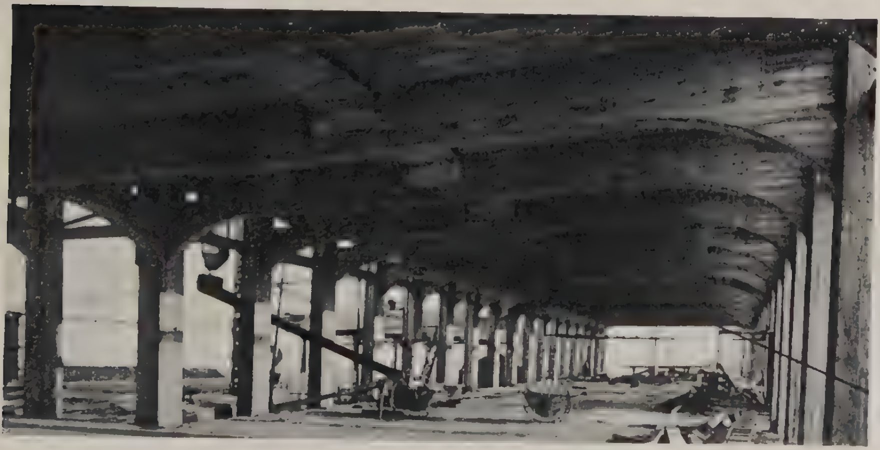


Fig. 186.—Interior View of Factory at Stoke-on-Trent.

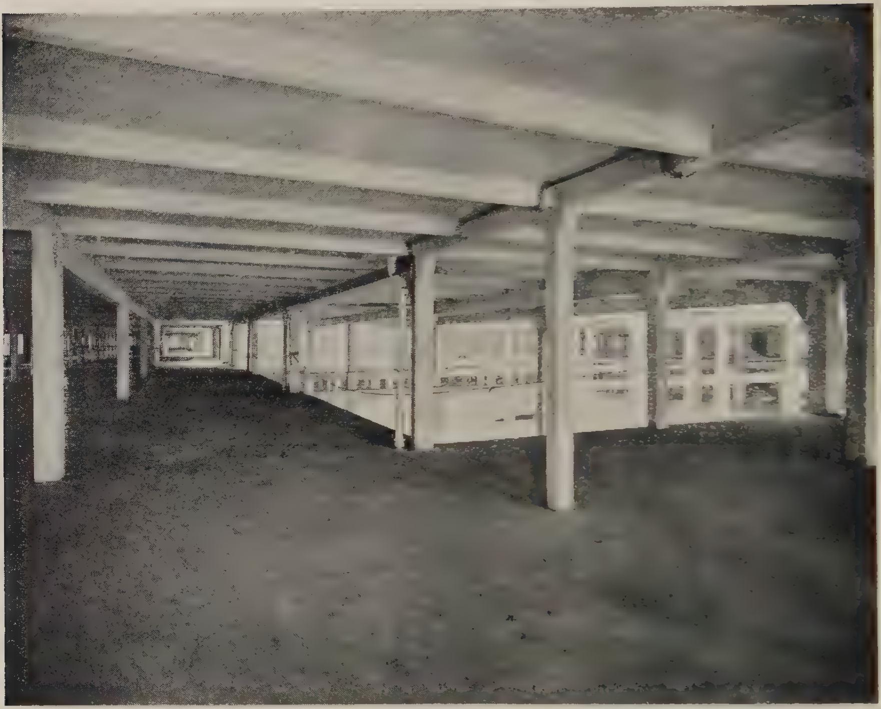


Fig. 187.—New Bridge Street Warehouse, Newcastle: Interior.

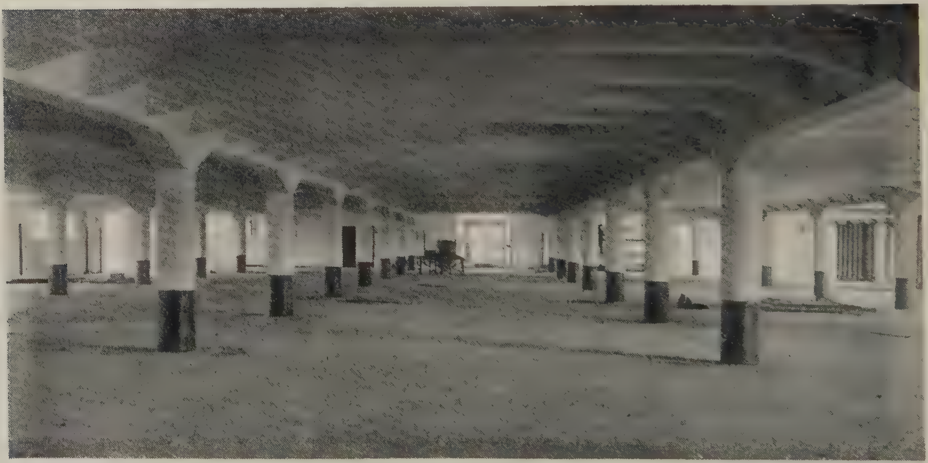


Fig. 188.—Transit Sheds: An Upper Floor.

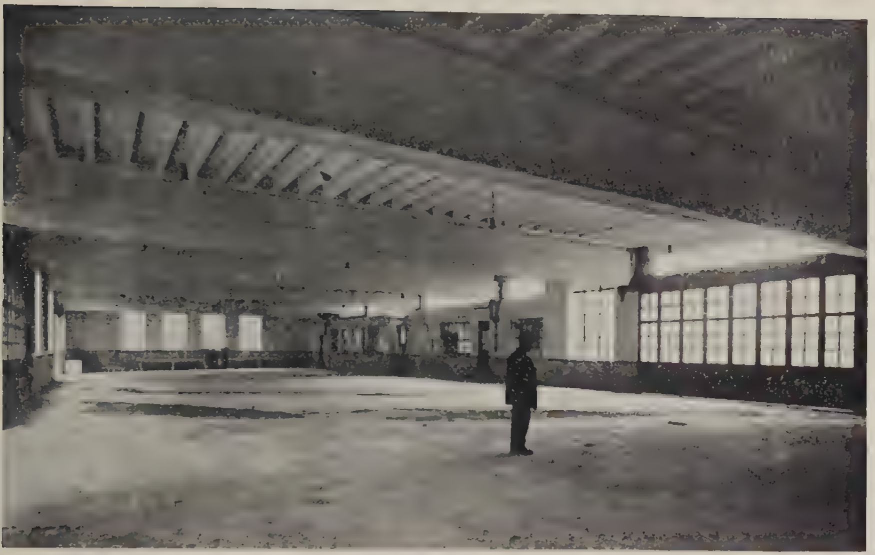


Fig. 189. Reinforced Concrete Fish Market at Cardiff.

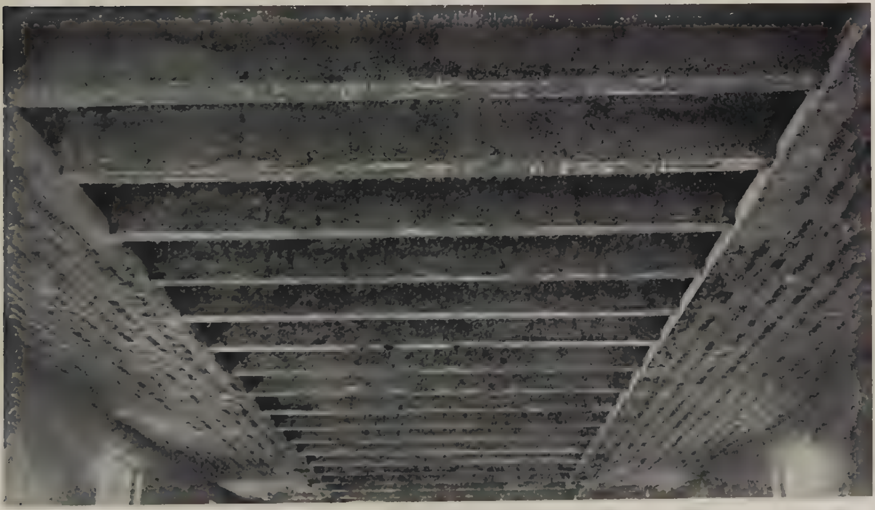


Fig. 190.—Hollow Concrete Floor at Derby Infirmary.

British practice. The method in which these floors support their load (*Fig.* 191) is that the portion extending out from the column deflects in an umbrella or saucer fashion, the upper surface being in tension over the column, and carries the central portion of the panel which deflects in the opposite manner. Although the quantity of concrete per sq. yd. of floor is somewhat greater than in a beam and slab design the cost of steel fixing is much less.

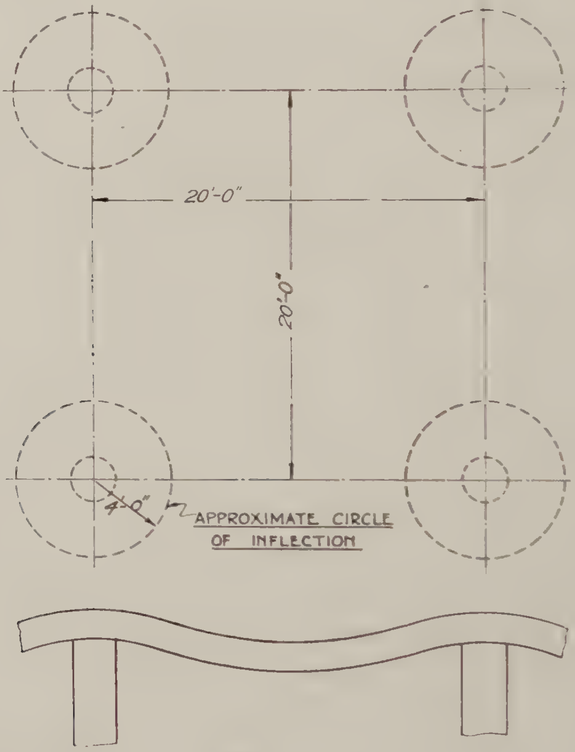


Fig. 191.

In hollow-tile floors the portion of the concrete above the upper surface of the tiles acts as the flange of the tee beam whose rib is formed by the concrete between the tile sides. It is important that the upper concrete be poured monolithic with the rib and under no consideration should a joint plane be left at the upper surface of the tiles. The upper concrete should not be less than 2 in. in thickness and the joists not less than 4 in. wide nor of less depth than will give a deflection of $\frac{1}{360}$th of the span if the ceiling is to be plastered. The flange of the main beam is usually constructed by

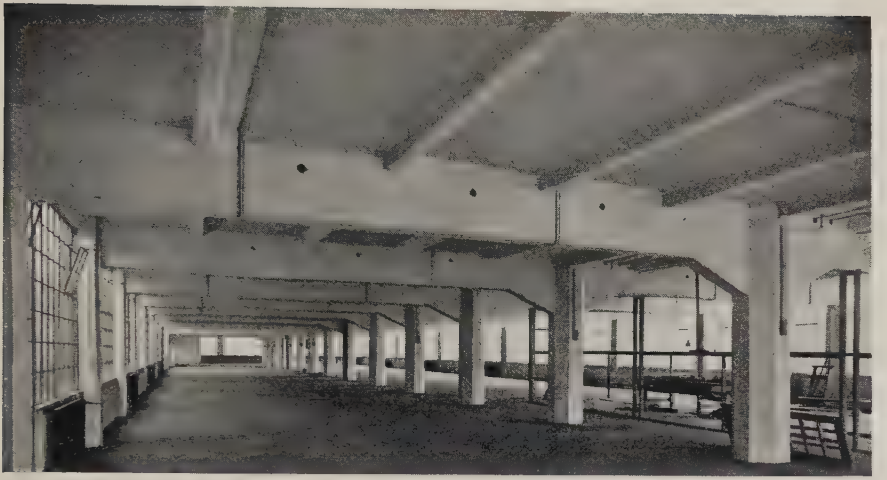


Fig. 192.—Reinforced Concrete Factory at Perth.

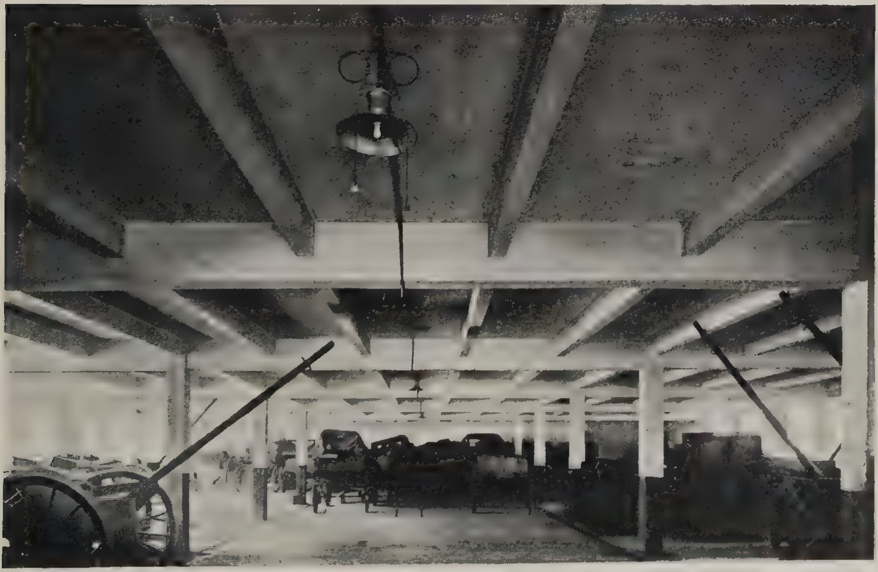


Fig. 193.—Reinforced Concrete Drill Hall at Nottingham.

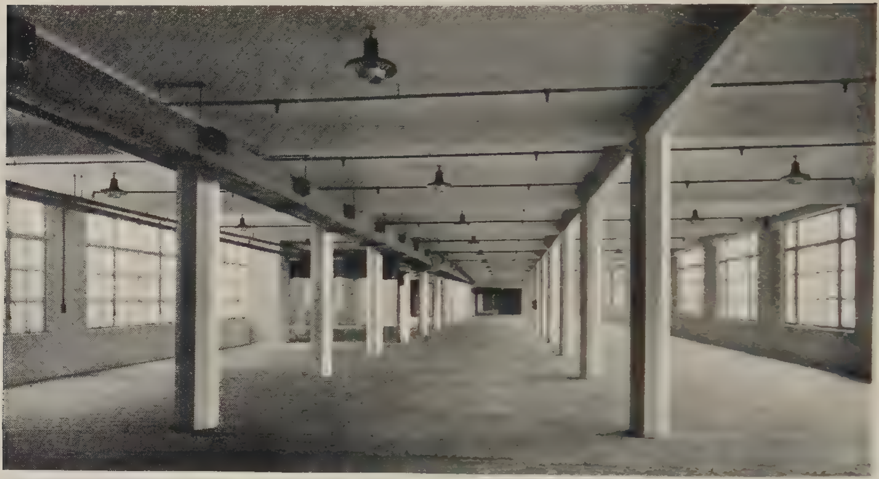


Fig. 194.—Interior of Reinforced Concrete Factory.

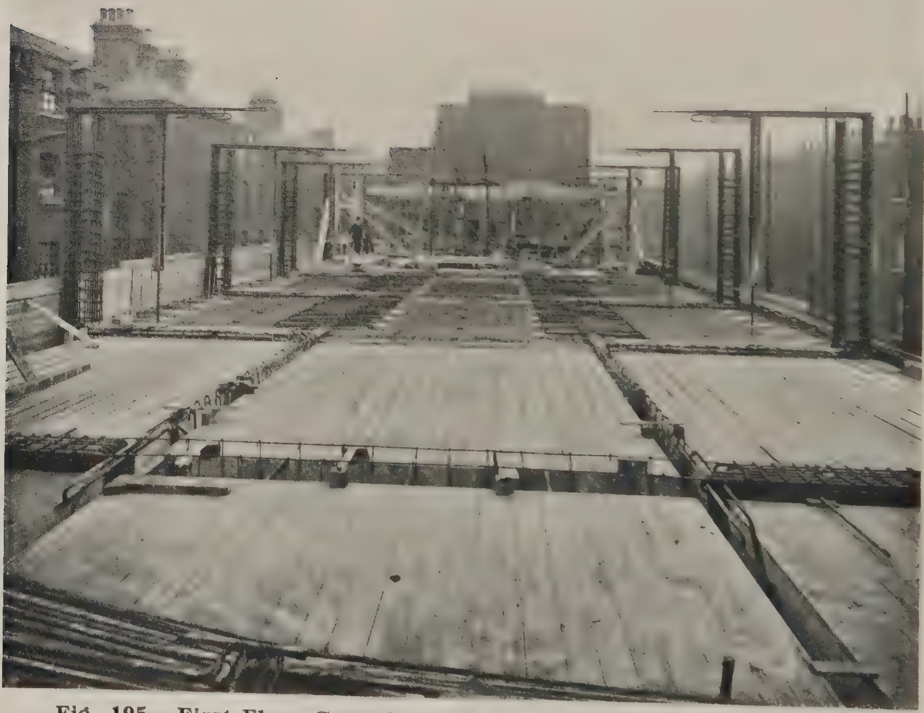


Fig. 195.—First Floor Centering with Part of the Reinforcement Laid.

omitting a tile on each side of its rib and filling in the space thus formed with reinforced concrete.

During late years steel tiles have been used for constructing light-weight floors ; of these there are two types differing only in thickness and in being used as forms only or as part of the permanent structure, in which case the tops and sides of the tiles are ribbed. One of the most generally used types of steel tiles is 20 in. wide at the bottom and when spaced at 25-in. centres allows for a 5-in. reinforced rib.

The formwork for this type of floor is very simple since it is only necessary to set a board under each rib to support the concrete and the edge of the tiles. In concreting such a floor the earthenware tiles should be thoroughly wetted before starting to pour the concrete else they will absorb some of the water necessary for the hydration of the cement. The coarse aggregate should not exceed $\frac{5}{8}$-in. size and ramming round the reinforcement in the joists must be very carefully and thoroughly carried out. If it is necessary to have a construction joint in the joist it should be placed over its centre.

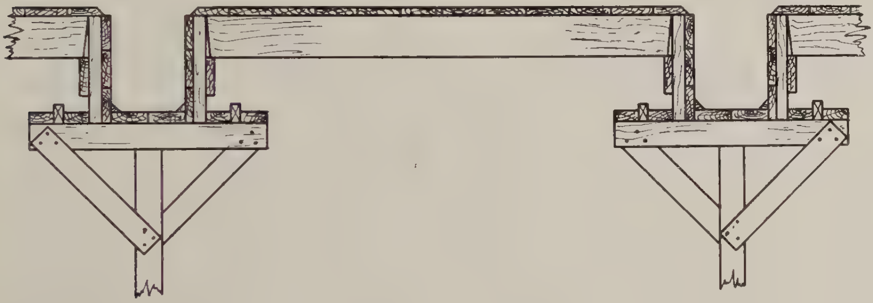


Fig. 196.

Formwork for beam and slab floors (*Fig.* 196) which was formerly left to the foreman carpenter to design is nowadays generally constructed from special designs with a view to economising in timber and labour and decreasing the cost of stripping and re-erecting the shuttering. Where, owing to repetition of a number of similar bays, floor shuttering can be used many times, it is customary to build the slab forms in panels the size of which will depend on the facilities for handling them. These panels are supported by the beam and girder sides and on joists and are made of a width about $\frac{3}{4}$ in. less than the clear width between the concrete of the beam sides. The sides of the panels are bevelled to ease stripping. The length of the joists is made $\frac{1}{2}$ in. less than the clear distance between the sides of the beam boxes. In constructing the main beam boxes the bottom board should, if too great a width is not required, be as wide as the beam bottom itself and cleats avoided. The bottom may be carried either on the column sheeting or off the yokes, the former being easier to strip. There are many possible arrangements of beam forms, the essential feature in design being the arrangement of the parts in such a manner that the beam bottoms and the posts supporting them can be left in position after the slab panels have been removed. General practice is to use 2-in. boards for beam bottoms. For the sides of beam boxes 1-in. or 1½-in. timber is usual, cleated at 18-in. or

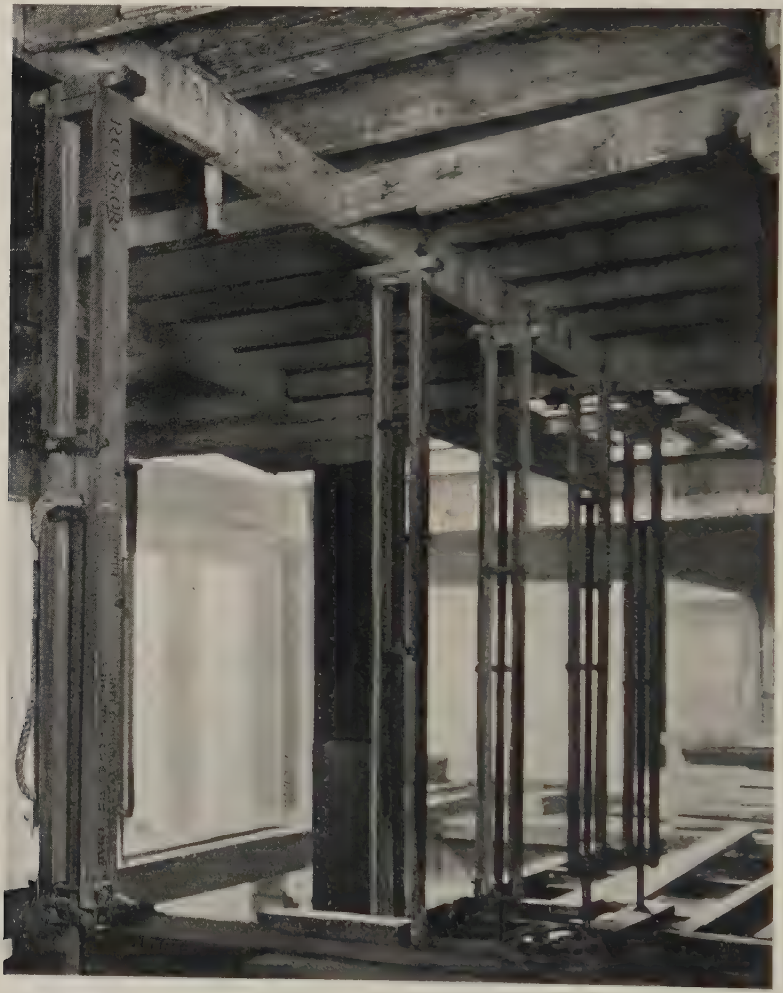


Fig. 197.—Form Supports.

24-in. centres where the depth of beam requires the use of two or more boards. These cleats or longitudinal strips nailed to them are used for supporting the joists of the floor panels. The beam sides must always overlap the bottoms and be tightened together with braces, wedges or clamps.

Where beam forms run into girder forms or girder forms into column forms, the sides of the member intersected must be cut away and the space left stiffened up with cleats round its sides and bottom edges. Where the corners of beams are to be bevelled a bevel-strip must be set inside the boxes. This strip is useful in permitting the easy removal of the forms and often saves the making-good otherwise required on arrises when jack-bars are required for loosening the boxes.

The proper bracing of all forms is essential in order to prevent them bulging under the pressure of the wet concrete. Girder and beam boxes should have a camber on the under side to allow for settlement of the supporting members and to prevent the appearance of a sag in the beam when completed.

In erection of forms care must be taken to avoid leaving spaces through which the finer constituents of the wet concrete may leak away. If any such openings appear while the concrete is being poured they may be caulked with strands of rope, plaster of Paris, or wood strips. Posts under beam and girder forms are fitted with folding wedges at their lower ends and caps at their tops.

Special adjustable posts (*Fig.* 197) save cutting or splicing timber when they are moved from one story to another where the headroom is different. Diagonal bracing between posts is necessary to keep the alignment true and stiffen the scaffolding against lateral displacement.

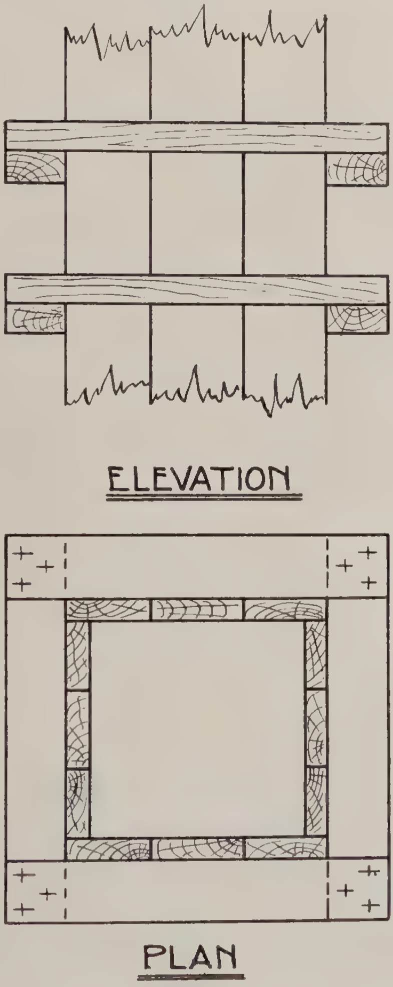


Fig. 198.

Wedges are usually cut from 4-in. by 2-in. hardwood such as beech or oak. Where the soil is of poor bearing capacity the wedges should rest on mud-sills made from two layers of 9-in. by 3-in. timber.

Column Forms.—Column forms may be built up complete before erection or one side may be left open and filled in as the concrete is poured. Column sheeting is generally clamped by 4-in. by 4-in. yokes and ⅝-in. bolts (*Fig.* 203) or by special metal clamps (*Fig.* 204) which are adjustable for various sizes of columns. If the forms are built up as a unit they should be inspected immediately before concreting the columns to ensure that shavings,

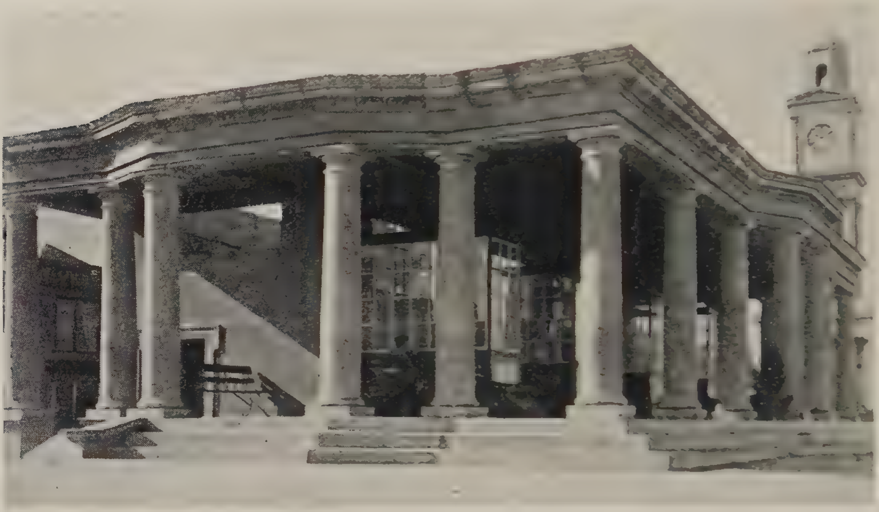


Fig. 199.—Concrete Shelter at Herne Bay.

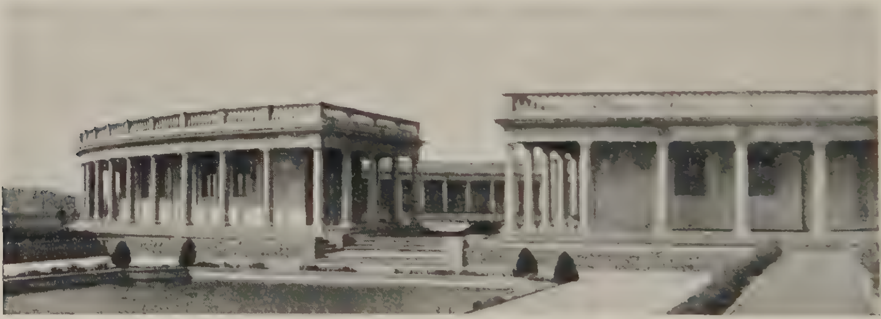


Fig. 200.—Reinforced Concrete Pavilion.

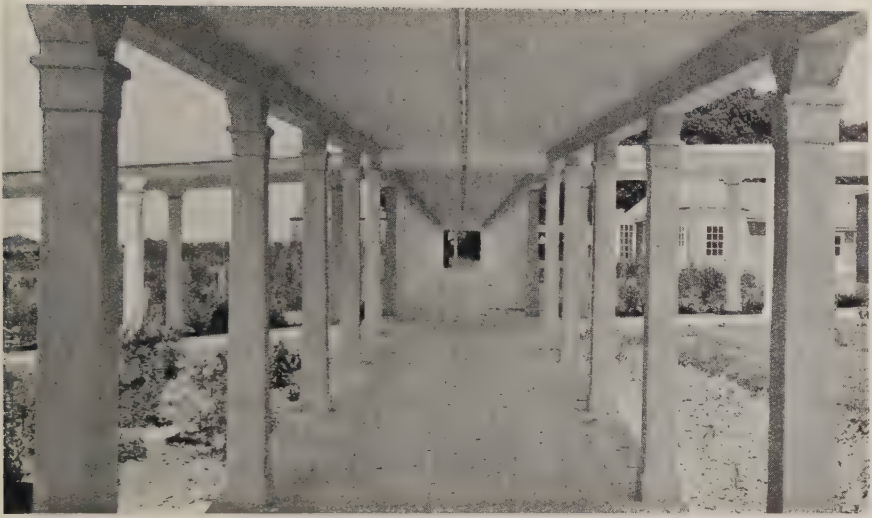


Fig. 201.—Reinforced Concrete Covered Way at Surrey County Sanatorium, Milford.

etc., have not been left in the bottom of the box. A cleaning-out gate should be provided in the bottom of each column box. Timber forms for circular columns are illustrated in *Fig.* 205.

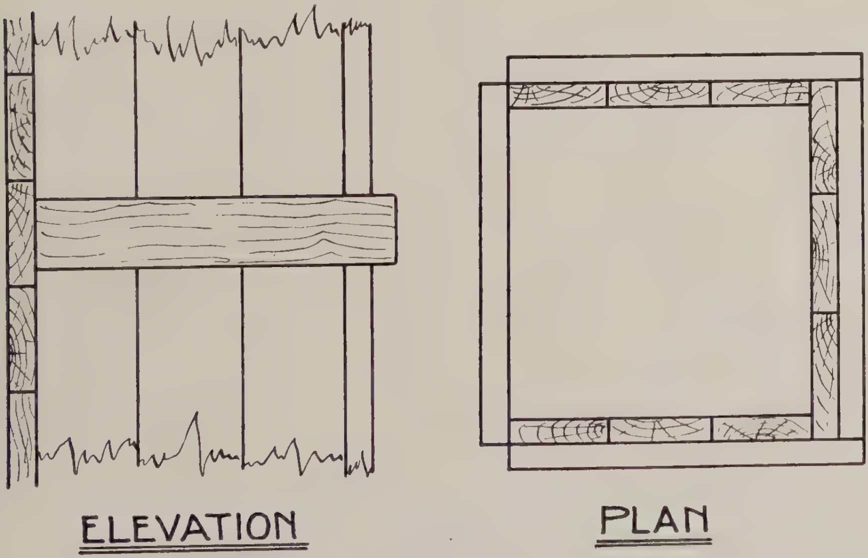


Fig. 202.

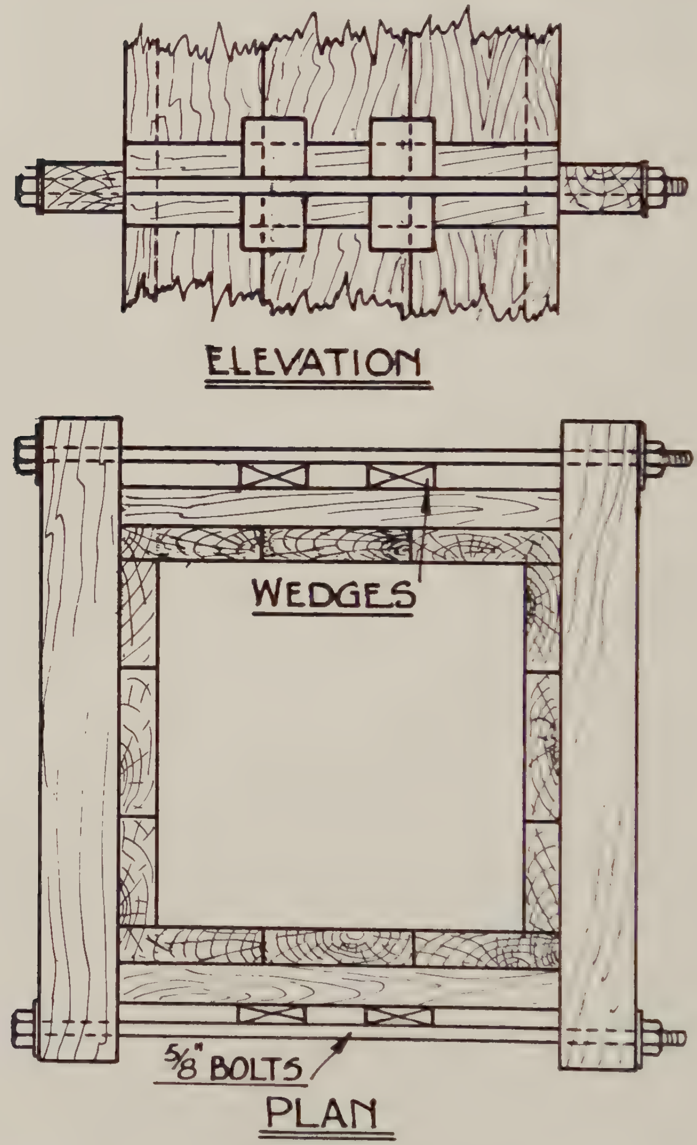

ELEVATION
WEDGES
5/8" BOLTS
PLAN

Fig. 203.

Slab Finishing.—When the slab is to be covered with a wearing surface other than concrete the latter is usually finished to the approximate level with shovels, the resulting surface being sufficiently uneven to provide a key for the overlying material which is to provide the real finish.

If the slab is not to have any material laid over it a screed finish is generally given. In this case wooden screed boards are temporarily set in the concrete to the exact level required. A screed board is then worked by two men over the surface of the concrete to level down the high places. Low places are usually filled in with a fine concrete by a third man. The motion of the screed board must be a combination of vertical and horizontal movements in order to secure an even surface.

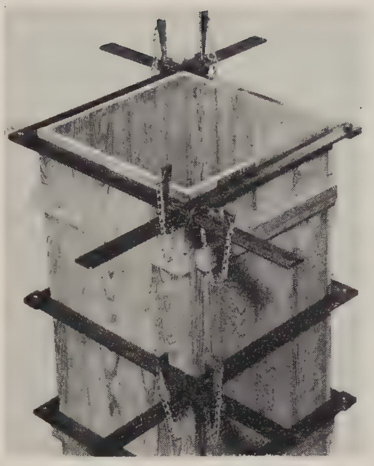


Fig. 204.—Column Clamps.

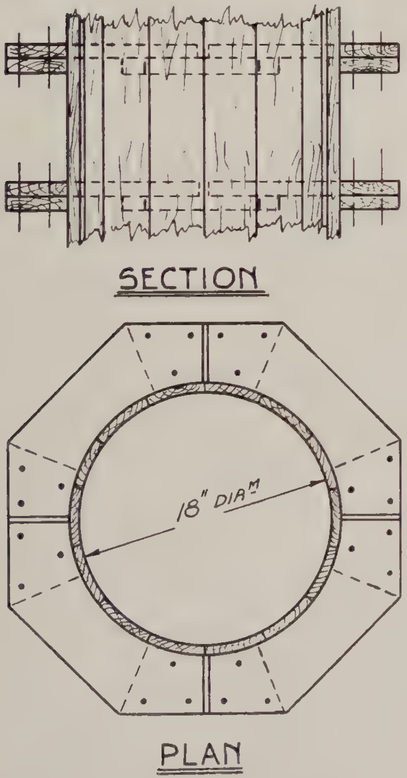


Fig. 205.

When a more even surface is required a wooden float may be used; the ordinary hand float produces quite a good surface, but it necessitates the use of a bridge of some kind in order to enable the workman to reach a large area of slab without standing on the freshly finished floor. Sometimes floats with long handles are used to obviate the employment of the movable bridge, but the result is not so good.

In roadwork a smoothing board or a canvas belt is often employed. Their use results in a surface comparable with that given by the wooden float. Where a high degree of smoothness is required the steel trowel, worked from a bridge, gives satisfactory results, especially if the top layer of concrete is a fine mix.

In ordinary reinforced concrete work a highly polished floor is seldom required, but where this is specified a carborundum grinding-stone, electrically operated, is generally employed. This process is described in detail in Part III.

Unreinforced ground-floor slabs are usually divided into squares with not more than 10-ft. sides by prearranged contraction joints. The latter must be carried down through the whole thickness of the slab.

Granolithic Finish.—The following notes, if carefully followed, will result in a floor with good wearing qualities, which will not be subject to troublesome disintegration or dusting :—

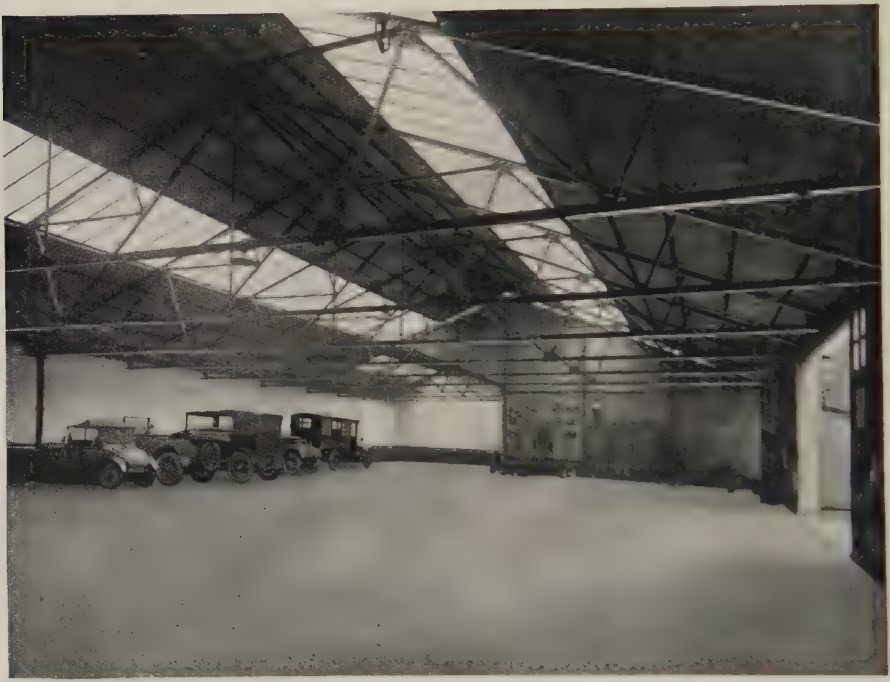


Fig. 206.—Reinforced Concrete Garage Floor.

Chips composed of granite or whinstone are suitable for granolithic floor surfaces, providing the particles are graded so that different sized particles from the smallest to the largest are present to result in greatest density. The grading reduces the proportion of voids in the aggregate, and as the voids must necessarily be filled with the cement paste the smaller the voids the less cement will be needed to produce a smooth surface.

Chips containing an excessive amount of fine dust should be avoided, as dust greatly reduces the strength of the concrete and tends to come to the surface on trowelling and so form a skin of very weak material which breaks up under traffic and causes dusting.

The choice of cement depends on the method and time of finishing. Cement with an initial setting time of 30 to 60 minutes will cause the finishing mixture to stiffen sufficiently soon to allow of the floor being finished the same day as laid. A slow-setting cement will cause the finishing to be delayed until the next day, when the material may have become too hard.

Laying.—The first consideration in laying is that a good bond should be made between the base course and the granolithic mixture. If the base concrete is freshly laid and in a green condition no special precautions need be taken. This condition of laying is ideal since a perfect bond is produced and the base concrete does not drain away the water from the granolithic mixture.

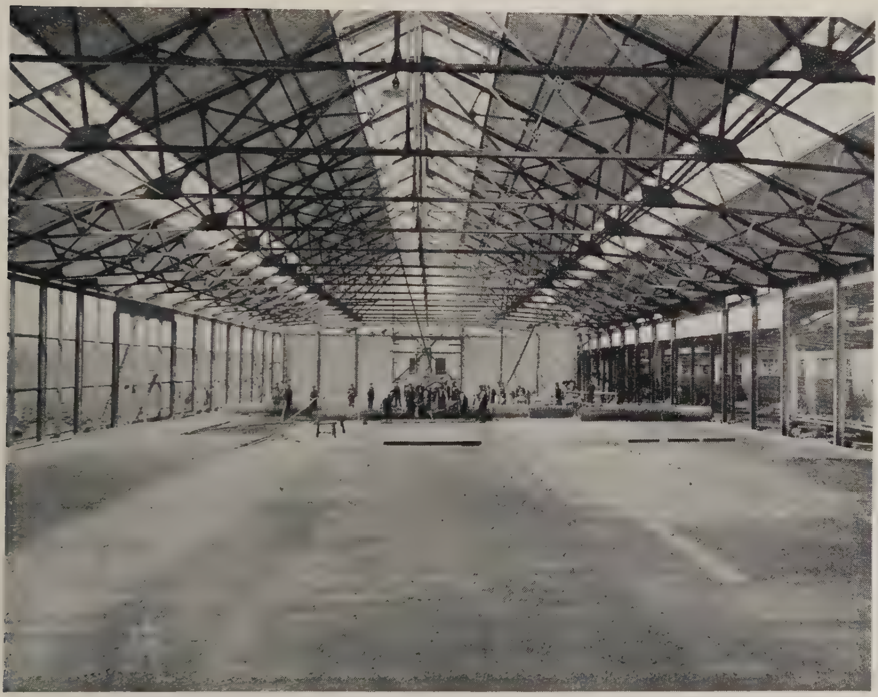


Fig. 207.—Reinforced Concrete Floor at Omnibus Garage.

If the concrete base is old it should be hacked and brushed and thoroughly soaked with water. The soaking is necessary to produce a good bond, and it also serves the important duty of preventing the absorption of water from the topping. The quicker concrete is dried out the poorer is its strength, and the comparative difficulty in obtaining good granolithic finishes on suspended floors compared with ground floors can be attributed only to the more rapid drying from the former. This makes the soaking of the base course even more important in the case of suspended floors.

Finishing.—That concrete should be disturbed after it has been put into position is against all theory and experience for the production of maximum strength. Yet the trowelling of floors, which is really a disturbance of the concrete, is necessary to produce a smooth finish. Trowelling, besides giving a smooth finish, improves the surface by consolidating it, but it does harm in as much as it interferes with the setting.

A further harmful action, especially attributable to over-trowelling, is that fine dust in the aggregate is brought to the top, and this tends to weaken the upper layer. Dusting is unknown in terazzo floors because the smooth surface is obtained by rubbing down after the setting has taken place so that the initial set is not disturbed and there can be no skin of fine material on the surface.

Fig. 208.—Reinforced Concrete Railway Warehouse at Brentford.

The chemical actions which cause the hardening of cement cannot take place in the absence of water; concrete increases but slightly in strength unless it remains damp. This damp treatment is of even greater importance in the case of a trowelled surface where the initial set has been disturbed, since the absence of moisture coupled with a partially destroyed set very strongly favours dusting.

Good Practice.—A procedure which should produce satisfactory results is as follows:

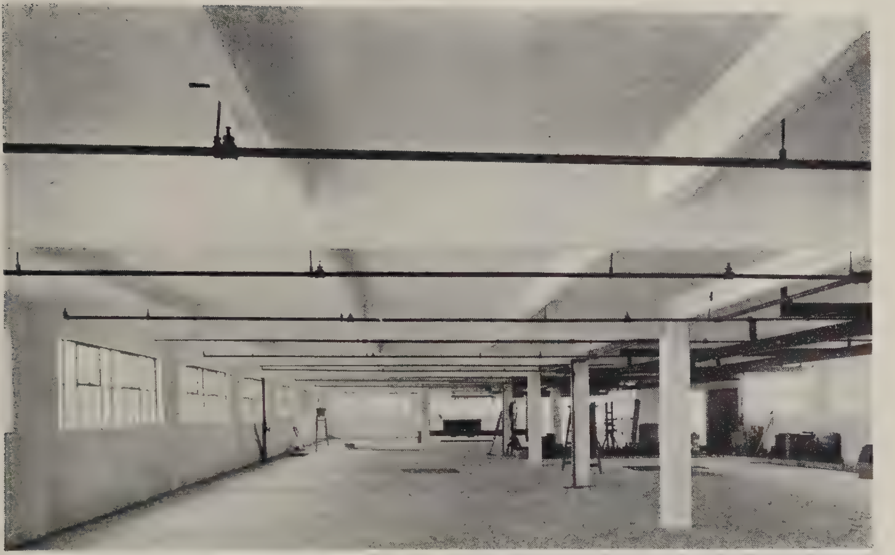


Fig. 209.—Reinforced Concrete Factory at Staines: View of Seventh Floor.

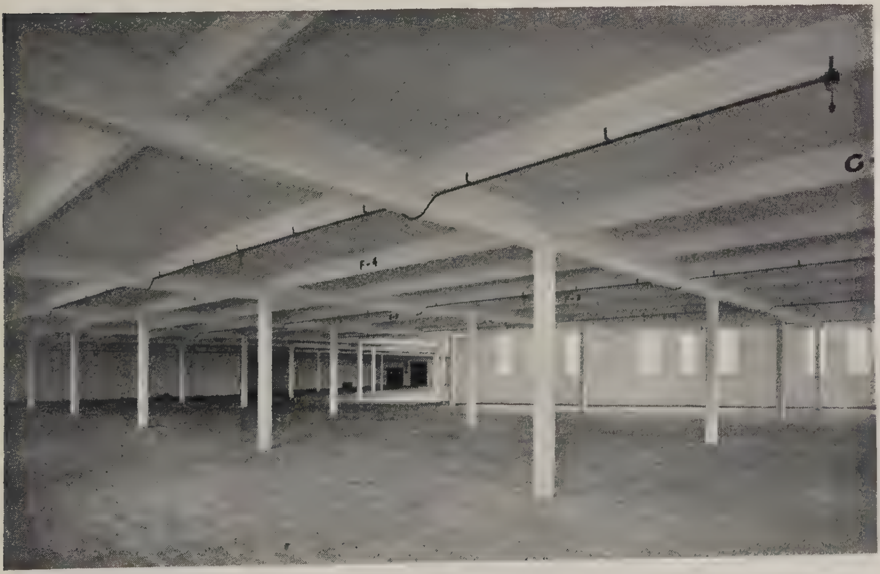


Fig. 210.—Interior of Reinforced Concrete Warehouse at Bristol.

(1) Produce a good key in the base concrete by hacking, brushing, and wetting.

(2) Make sure that the base concrete is thoroughly soaked, thereby preventing the water in the topping from being drained away.

(3) Use clean well-graded chippings. If these are not of good quality the floor will be liable to dusting.

(4) Trowel as little as possible and as early as possible, i.e. when the material has stiffened just sufficiently to allow the marks to be smoothed out.

(5) Keep the floor moist for about 10 days, or 4 days if "Ferrocrete" is used, by covering with a layer of damp sand. Wetting the floor daily with a hose and allowing it to dry out between times is not recommended as good practice. Disused sacking for this purpose is supplied at a nominal price by the Cement Marketing Co. Ltd.

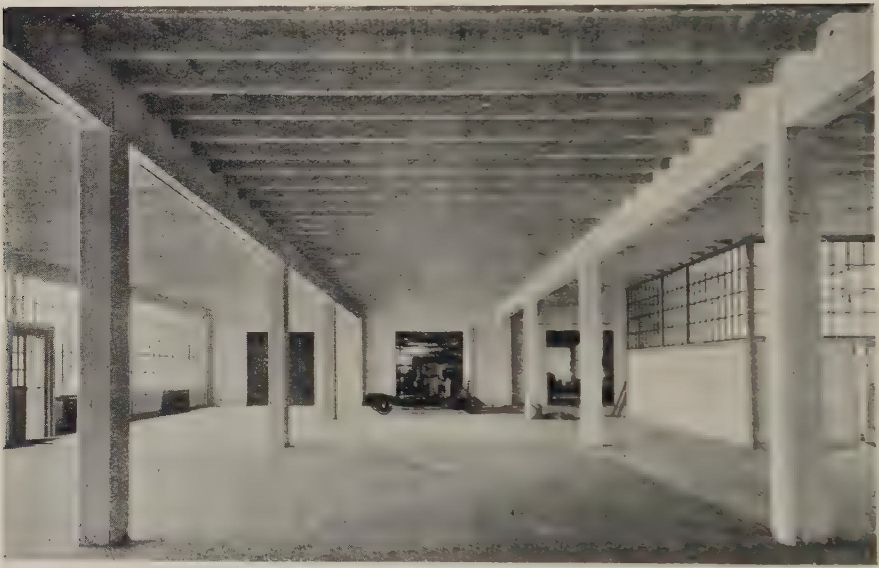


Fig. 211.—Reinforced Concrete Motor Factory at Luton.

Dust Proofing.—In order to make an existing concrete floor absolutely dust-proof the surface is prepared for treatment by thorough cleansing with clean water and then treated with silicate of soda. To get the best penetration the concrete must be thoroughly dry, especially before the first application, and if practical it is well to let it dry for several days after the first scrubbing.

The silicate solution is made up immediately before using (1 gallon of silicate of soda solution is diluted with 4 gallons of water, and the resulting 5 gallons will cover 1,000 sq. ft. of surface with one coat). The solution may be applied with a mop or hair broom, and must be continuously brushed over the surface for several minutes to obtain an even penetration.

An interval of twenty-four hours should be allowed for the surface to harden, after which it is scrubbed with clean water and allowed to dry for the second application. Three applications made in this manner will usually suffice. When properly applied the treatment gives a very hard surface that is uniform in appearance.

Various arrangements of beams and columns for beam and slab floors are illustrated in *Figs.* 186 to 189 and in *Figs.* 192 to 194 and elsewhere. *Fig.* 184 shows a completed flat-slab floor supported by round columns with drop panels. A type of hollow-floor is illustrated in *Fig.* 213.

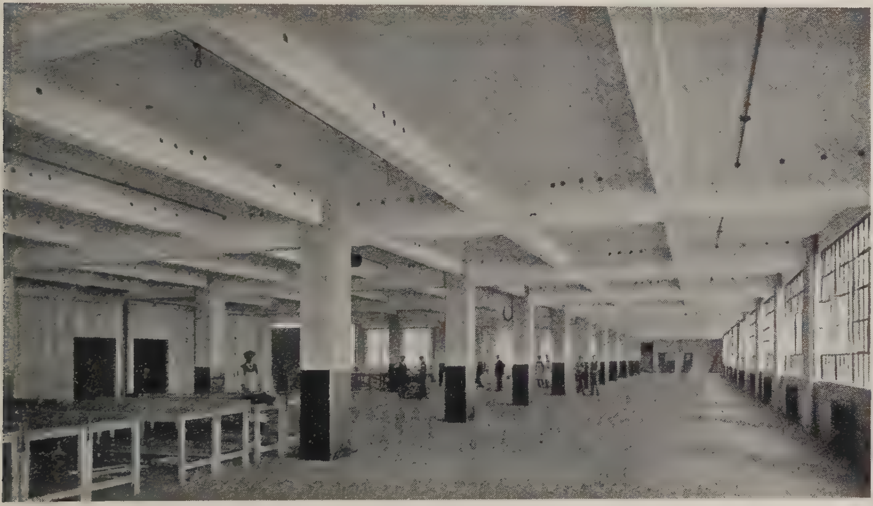


Fig. 212.—Reinforced Concrete Factory at Hayes.

Columns

There are two methods of arranging the lateral reinforcement of columns, (*a*) using closed links or hoops, and (*b*) using a continuous spiral with a closer pitch. So far as possible column steel should be assembled on the bench and erected as a unit. Even in very small columns the use of bars of less than $\frac{5}{8}$-in. diameter is not to be recommended. It is important to allow ample cover of concrete in the vertical bars and hoops and to see that the reinforcement is arranged centrally in the column forms. The rigid tying of junctions between hoops and vertical bars is essential else the hoops will certainly be displaced during tamping of the concrete.

Dowels are best made as in *Fig.* 214, an arrangement which is preferable to having separate short lengths of bars with right-angle bends. It is easier

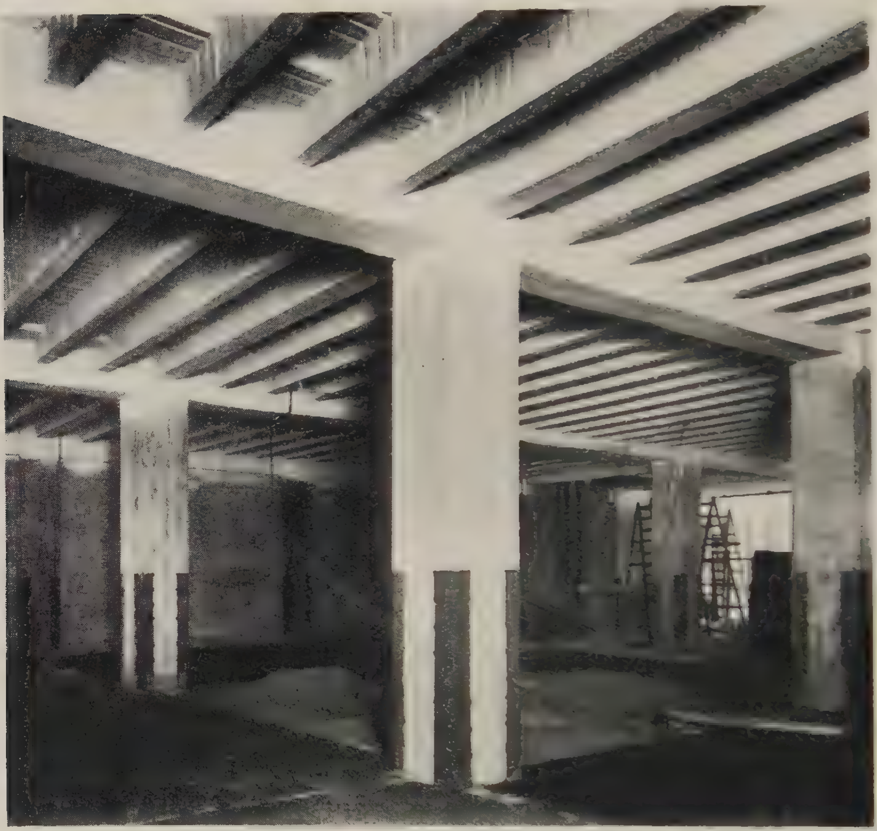


Fig. 213.—Interior of Large London Reinforced Concrete Warehouse.

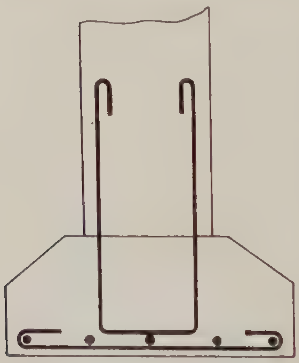


Fig. 214.

to keep two bars in place than four while pouring concrete. Generally the column hoops will be too large to fit neatly around the dowels, and temporary wooden spacers are used to hold the bars in their correct position.

Protection of Column Corners.—In warehouse construction, where provision is required against damage to the arrises of columns when trucks collide with the columns or heavy packing cases are dumped against them, it is usual to cast steel angles at the column corners. These angles should extend 3 or 4 feet above the floor level. *Fig.* 213 illustrates a new column guard made from

$\frac{3}{16}$-in. steel plates in 4-ft. lengths, each side being 6 in. wide and tapped for three $\frac{3}{8}$-in. bolts which fix the guard to the concrete column. The edges of the bent plate are cut so as to form prongs $4\frac{1}{4}$ in. long and $\frac{1}{2}$ in. wide and bent outward at an angle of about 45 degrees. The prongs provide an efficient connection between the plates and the concrete.

Fig. 215.

Concreting Columns.—On small jobs the concrete may be raised by bucket or hopper fitted with a bottom gate, suspended by a block and tackle from a tripod of timber, the latter being portable and easily moved from column to column. If scaffolding has been erected round the site of the building a "cat-head" may be used for raising the concrete or a hoist can be erected. Care must be taken to tamp the concrete thoroughly in order to make it surround the reinforcement properly and prevent honeycombing. Too dry a mixture may result in the production of air-holes.

Concreting Upper Stories

In factory buildings and warehouses of reinforced concrete, a hoist, tower or mast (*Figs.* 215–7) is generally the cheapest form of plant to use for raising and distributing concrete. When the layout of the building is a long narrow rectangle two or more pouring plants may be used simultaneously. Sometimes there are portions of the floor which are outside the reach of the pouring plant; in such cases the concrete is generally discharged from the hoist bucket into a timber or steel portable hopper from which it may be drawn off as required to fill the concrete carts or barrows. When concreting beams the concrete is often discharged first into portable shallow wooden trays resting on the slab formwork. This prevents the latter getting coated with a layer of set concrete before it is time to pour the slab.

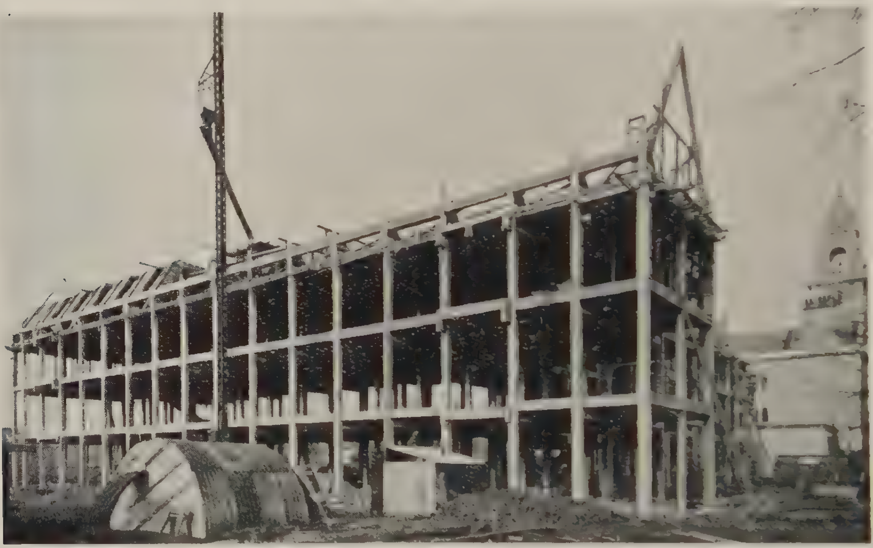


Fig. 216.

Before any concrete is poured the beam or column boxes should be inspected to discover if any shavings, etc., have been left in them and the steel work should be passed by the clerk of works. Some specifications require the slab and beam to be poured as a unit, but experience has shown that it is safe to leave a horizontal joint about 1 in. below the level of the bottom of the slab. The latter method is also less costly.

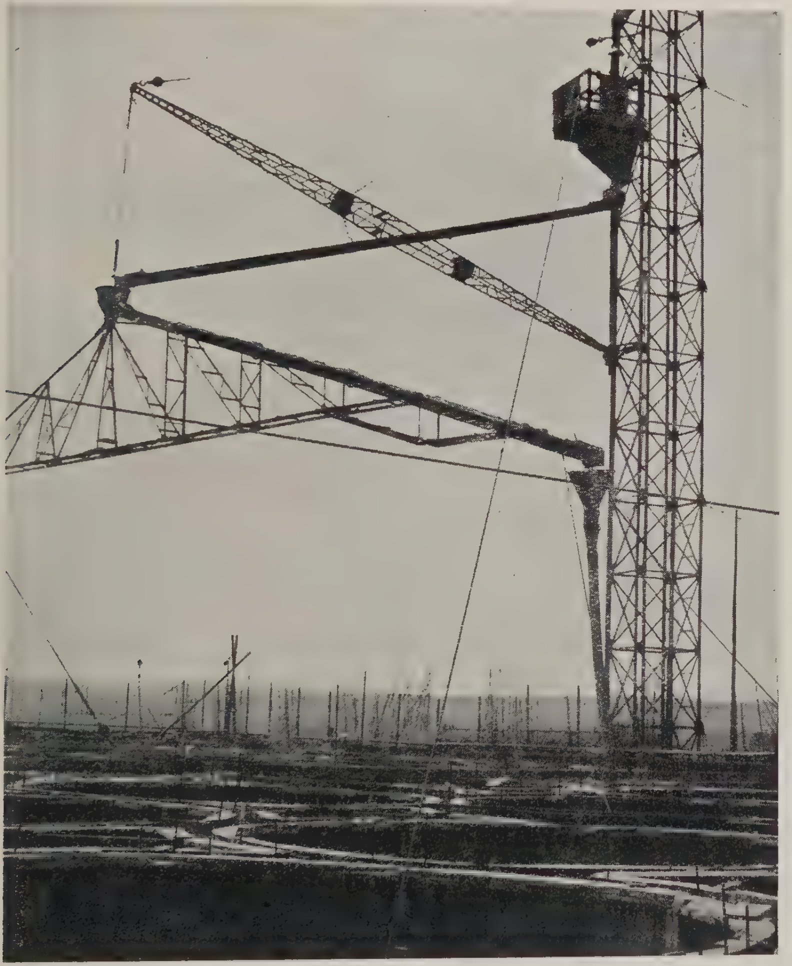


Fig. 217.

The periods which should be allowed between concreting and stripping the forms vary with the portion of the structure, the kind of cement used and the weather conditions. Under average conditions the following periods will prove satisfactory;

Portion of Structure.	Ordinary Portland Cement Concrete.	"Ferrocrete" Rapid-hardening Portland Cement Concrete.
Vertical walls	2–3 days	1 day
Columns	2–3 days	1 day
Floor slabs	14–28 days	2–4 days
Bottoms of secondary beams	14 days	3–4 days
Bottoms of main beams	28 days	6–7 days

Balconies

The large number of picture-houses which have been built during the last twenty years provide some excellent examples of the use of reinforced concrete in the construction of balconies. This is a class of work which introduces many difficult problems in design since the view of the screen from below the balcony must not be obstructed. Where columns are permissible the balcony may be designed as a sloping slab spanning between main beams whose direction is parallel to the long axis of the theatre. In order to accommodate the rows of seats the upper surface of this slab is stepped, the tread being about 30 in. and the rise arranged so as to give an unobstructed view from all seats. In order to avoid placing columns under the parapet beam of the gallery the front portions of the balcony main beams are often cantilevered beyond the front column. Another arrangement which has been adopted in some cases is to have one column only under the middle of the main beam which becomes a double cantilever. In order to allow for the front rows of seats being filled while the others are still vacant the back end of the cantilever is provided with steel ties anchoring it to the wall or pilaster at the back and preventing any tendency to rotate.

In order to reduce the size of the columns a high percentage of steel and a rich concrete may be used.

If columns are to be omitted the main beams must span from side wall to side wall and may require to be of considerable depth if the span is great. It is, however, of importance not to make the beams narrow else the cost of placing and ramming the concrete will be excessive. The front, or fascia, beam of the balcony projecting above the slab will usually be of sufficient depth to serve as a support for portion of the gallery slab, or its depth may be increased, if necessary, by adding an extension below the slab.

Formwork.—For details of formwork see p. 173.

Concreting.—See Part II for concreting of floors and beams and Part III for surface finishing.

Fig. 218 shows a completed balcony.

Reinforced Concrete Roofs

Flat roofs are generally designed and constructed in a similar manner to that adopted for the floors below. A point worth consideration is that although the live loads are of much less intensity it often pays to make the beams of the same cross-section in the roof as in the floor because the same formwork may be used.

It is usual to give the upper surface of the slab a fall to the edges in order to provide drainage. The roof is often left uncovered, but some engineers specify that asphalt, roofing felt or similar material shall be laid.

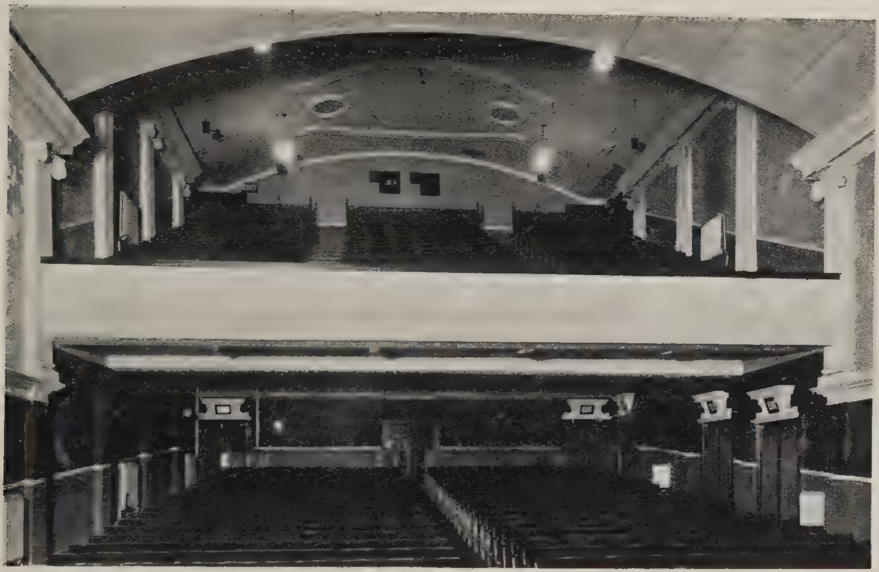


Fig. 218.—Reinforced Concrete Balcony at Picture Theatre.

Some form of insulating material is useful in preventing condensation and is cheaper than providing a suspended ceiling. Where the roof slab meets a vertical surface such as a parapet wall or elevator house casing flashing must be provided to prevent leakage of water.

In factory construction a saw-tooth roof is often used with cast *in situ* reinforced concrete trusses (*Fig.* 219). *Figs.* 220 and 221 show formwork erected for saw-tooth or north-light roofs.

Small square buildings may be roofed in pyramid fashion and give a pleasing effect, but their cost is somewhat high owing to the complicated forms and supports required.

In designing roofs the following loads may be taken as ample.

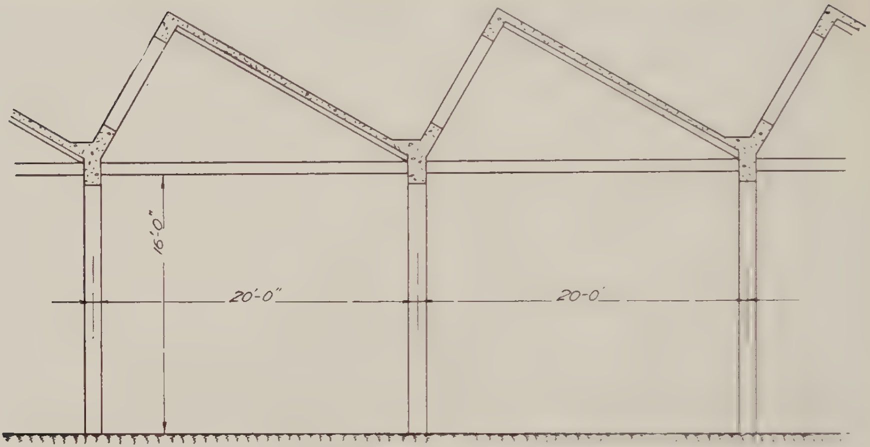


Fig. 219.

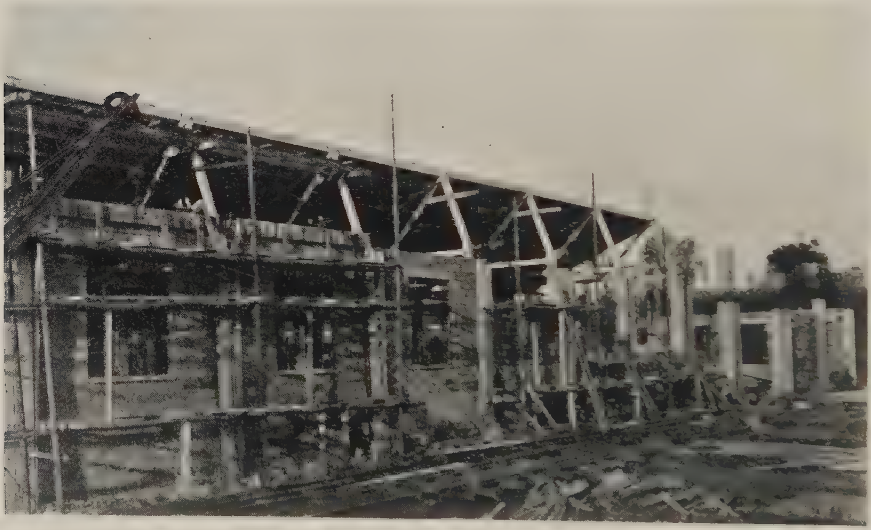


Fig. 220.—Reinforced Concrete Saw-Tooth Roof at Engine Sheds at Exeter.

ROOF LOADS.

Superimposed Loads.

Flat roofs or roofs up to 20 deg. pitch	56 lbs. per sq. ft. of surface, measured on a horizontal plane, including wind.
Roofs over 20 deg. pitch	28 lbs. per sq. ft. of sloping surface, including wind.

Dead or Structure Loads additional to above.

DESCRIPTION.	WEIGHT IN LBS. PER SQ. FT.
Asphalt	12
Boarding	$3\frac{1}{2}$ (per inch thickness)
Roofing felt	$\frac{1}{2}$
Slate battens	1
Slates	7–9
Tiles	12–18 (higher figure for small, i.e., plain tiles)
Glass	$3\frac{1}{2}$ (per $\frac{1}{4}$-in. thickness)
Glazing bars (metal)	3
Lead	5–7 (add for rolls)
Steel purlins	2–4
Timber rafter and purlins	7
G.I. corrugated sheeting (22–18 gauge)	2–3
Concrete and ceilings	(see "Floor Loads," page 165)
Asbestos slates	$2\frac{1}{2}$–3
,, corrugated sheeting	3–$3\frac{1}{2}$
Steel truss (approx.)	Total wt. $= 0{\cdot}75\,C.S.\left(1 + \frac{S}{10}\right)$ lbs. C = centre of trusses in feet. S = span of trusses in feet.

Spans of from 25 ft. to 35 ft. are often roofed as illustrated in *Fig.* 222. Large span roofs such as occur in industrial buildings are best designed monolithic with the columns to act as rigid frames. An economical spacing of the columns varies from 15 to 20 ft. for long span trusses. The curved roof with a tie rod of reinforced concrete is also used in this type of construction. Care is required to design the columns to resist the bending moment which may be brought on them by the wind. For exhibition buildings the type of roof in *Fig.* 223 gives a pleasing appearance and provides excellent lighting.

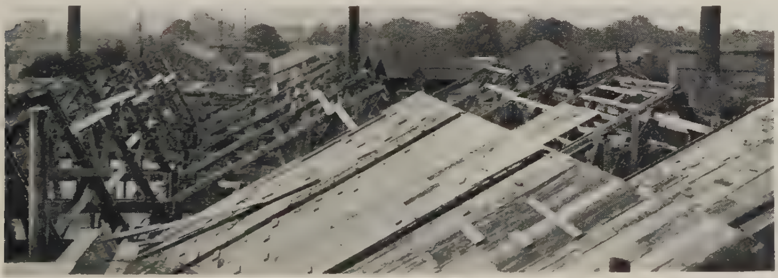


Fig. 221.—Saw-Tooth Roof at Staines.

The umbrella type of roof has been used to a large extent on the Continent

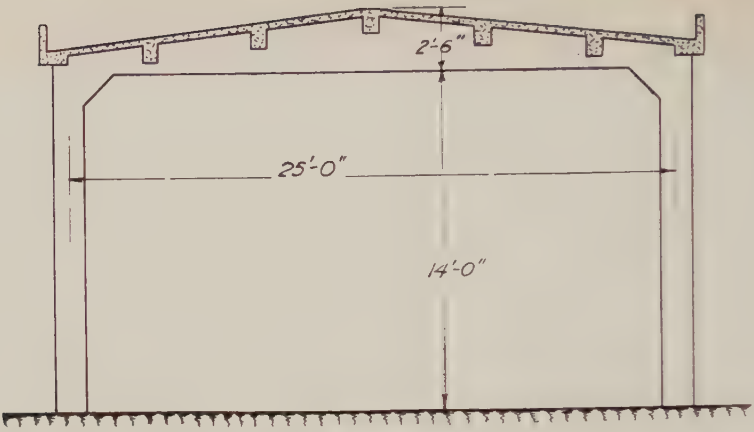


Fig. 222.

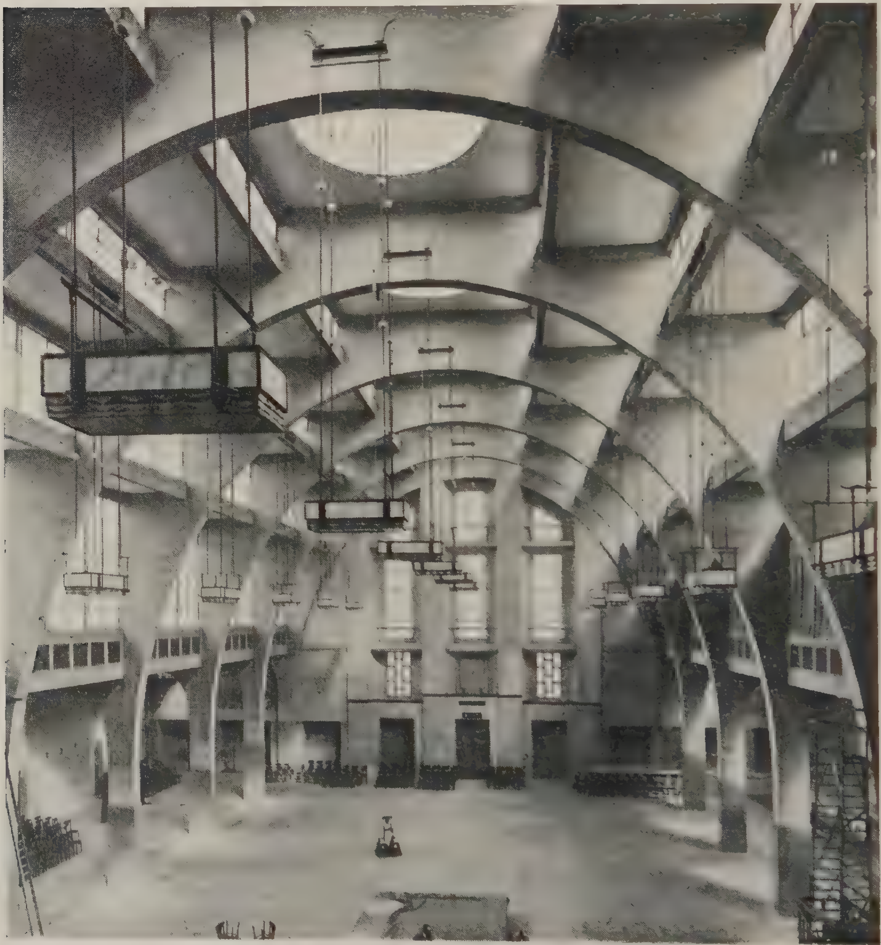


Fig. 223.—Royal Horticultural Hall, Westminster : Interior of Main Hall.

for railway platforms. The two-column type (*Fig.* 224) is another type of roof which has been successfully copied in reinforced concrete for railway work. The use of concrete in such cases greatly diminishes the permanent charges for painting and other maintenance which is particularly high in the neighbourhood of railway stations. The majority of these roofs have been constructed *in situ*, but in some cases columns, beams and purlins have been erected first and covered later with pre-cast reinforced concrete slabs. In casting slabs provision is made for lifting eyes and some reinforcement against stresses due to handling them.

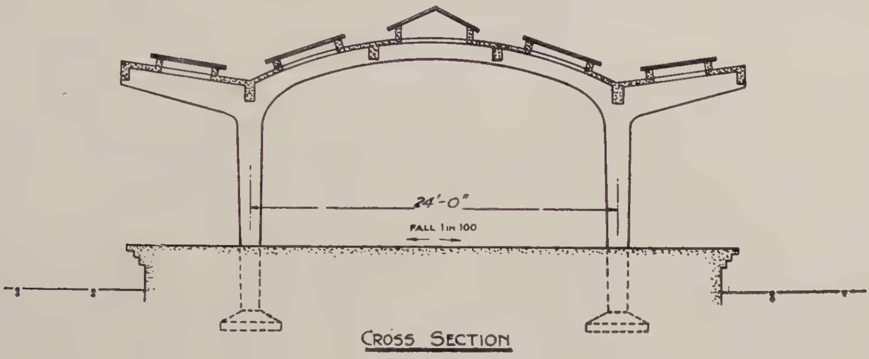


Fig. 224.

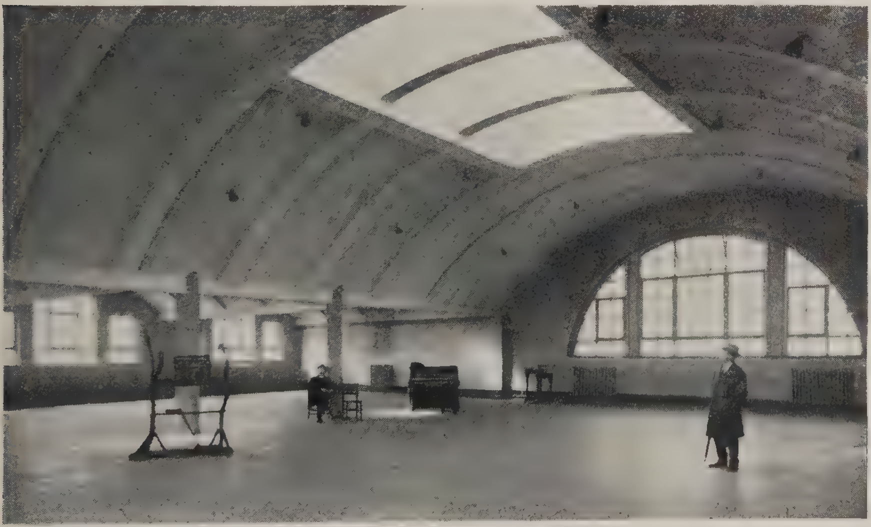


Fig. 225.—West Derby Street Schools, Liverpool.

Roofs with curved outlines (*Figs.* 224 to 226) may be designed as curved ribs between which reinforced concrete purlins carrying the slab span. The horizontal reaction may be taken by a tension member or by columns capable of resisting bending in addition to compression.

Staircases

Reinforced concrete stairs are constructed in four common types, (1) as pre-cast steps cantilevered from walls in the same way as the stone steps of an earlier period, (2) as pre-cast steps spanning between reinforced concrete stringers, (3) as slabs spanning from landing to landing, and (4) as tee beams. The last type of construction is useful for narrow stairs. The first type has been considered in the chapter on pre-cast work, in the second the stringers are designed as singly reinforced beams with recesses in the sides into which the steps fit. By far the most common class of stairs is that in which the slab spans between landings and is constructed after the completion of the floors of the building, recesses being left in the beam at the edges of the landing into which the slab is bonded.

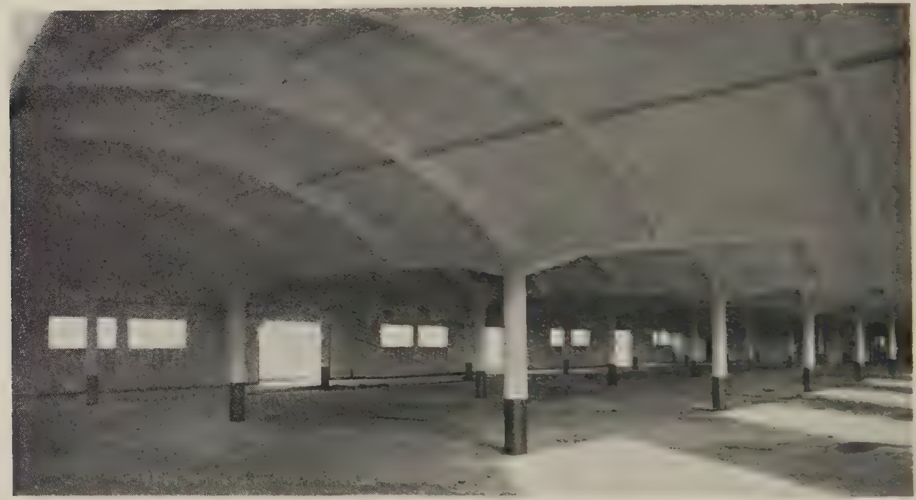
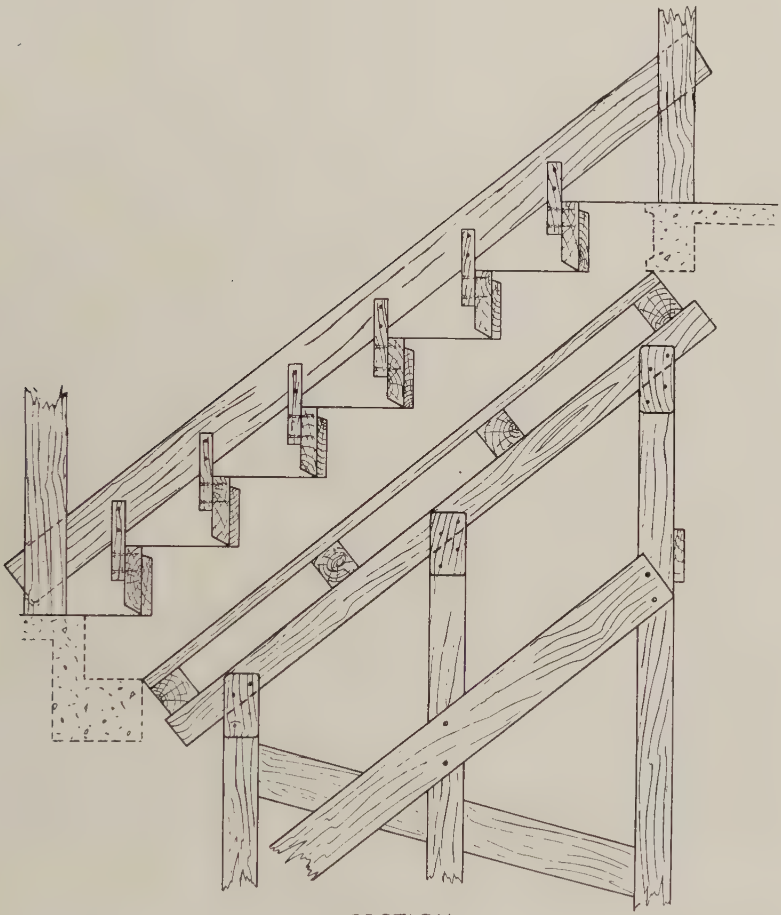


Fig. 226.—Transit Sheds : Roof Story.

In the design of stairs the live load is often taken as from 100 to 120 lbs. per sq. ft. in order to allow for heavy packing cases, safes, etc., being brought up the stairs. The effective depth of the slab is that shown by the distance x in *Fig.* 228 and the span is the horizontal distance between the supports of the slab. In order to allow of a granolithic or other wearing surface the actual height of the concrete riser must be less than that of the finished step by 1 in. or whatever thickness of finish is specified.

Wide staircases may be given additional support by stringers under the edges of the slab and the slab may be reinforced in two directions.



SECTION

Fig. 227.

Formwork.—An example of shuttering for slab stairs between walls is shown in *Fig. 227*. The slab is cast on a panel of 1-in. or 1¼-in. boards with joists at right angles to the direction of the boards. The joists bear on timber stringers which are supported by 4-in. by 4-in. posts cleated to them and with wedges at their lower ends. The illustration also shows how the nosing is obtained. The front boards to the risers are hung from timber stringers as shown.

Concreting.—A fairly stiff mix is desirable and if the stairs are to be very wide the riser boards must be prevented from bulging outwards. Top forms are usually unnecessary. The granolithic finish should be placed before the main concrete has hardened and the forms not removed for at least 7 days.

Steel Encased in Concrete

There are many reasons why structural steel should be encased in concrete. Concrete is unaffected by weather conditions and protects steel buried in it and which if uncovered would require frequent expenditure for maintenance. In industrial works structural steel is often badly damaged by gases and steam, but concrete is proof against these destructive agencies. The advantages to be gained in making structural steel fire-resisting have already been mentioned. In buildings subject to vibration the added weight of the concrete is very effective in reducing the vibration.

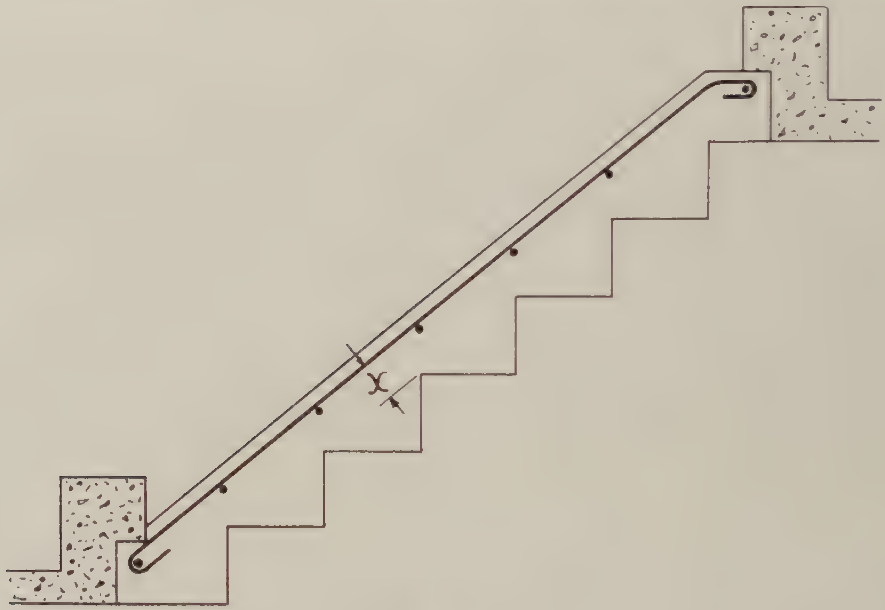


Fig. 228.

The extra strength conferred on stanchions and joists which are encased in concrete is a matter of extreme importance and has been fully tested at the National Physical Laboratory. It was discovered that casing 4-in. by 3-in. steel stanchions, 193 in. in length, so that the concrete section was approximately 8 in. square, increased the ultimate load on the stanchion from about 5 tons, for a plain stanchion, to 55 tons for the encased test specimen. When beams are encased so as to provide some inches of concrete above the top flanges there is also a marked improvement in the load-carrying capacity of the floor. With suitable safeguards building regulations might be amended in order to allow of advantage being taken of the increased strength supplied by the concrete.

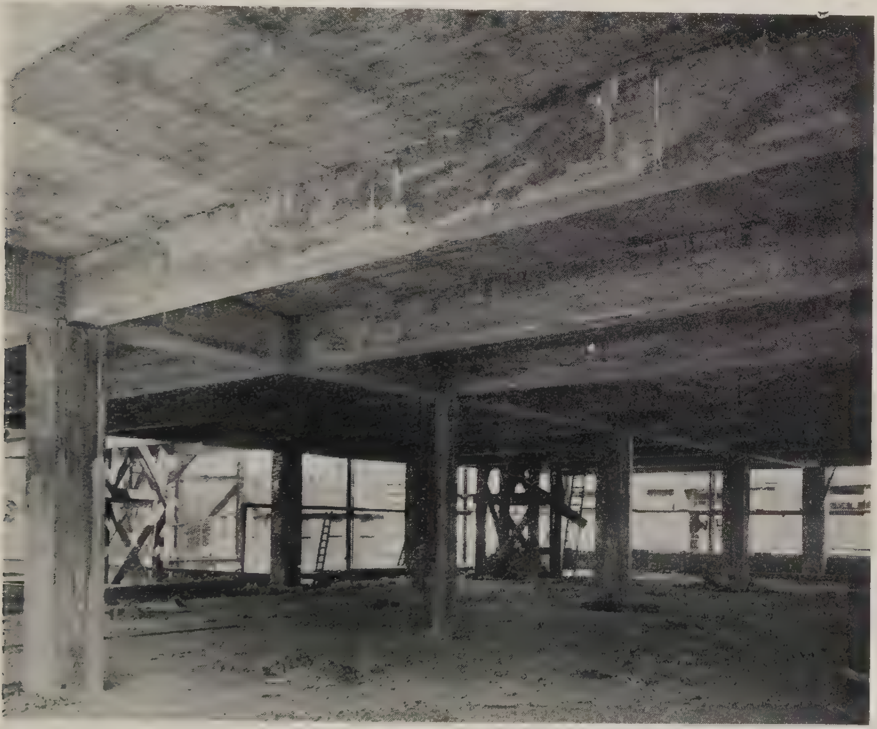


Fig. 229.—Concrete-Encased Steel at an Acton Factory.

Fig. 229 shows a factory building in which the steel has been encased in concrete.

Domes and Vaulted Ceilings

There are in general two methods of designing reinforced concrete domes, (1) as a number of arched ribs between which curved slabs span and the springings of which are tied into a circular beam and (2) as thin shells without ribs. The latter may be hemispherical or comprise more than one-half of the sphere. The design of the first class is similar to that of a series of arched ribs, but the second requires special consideration.

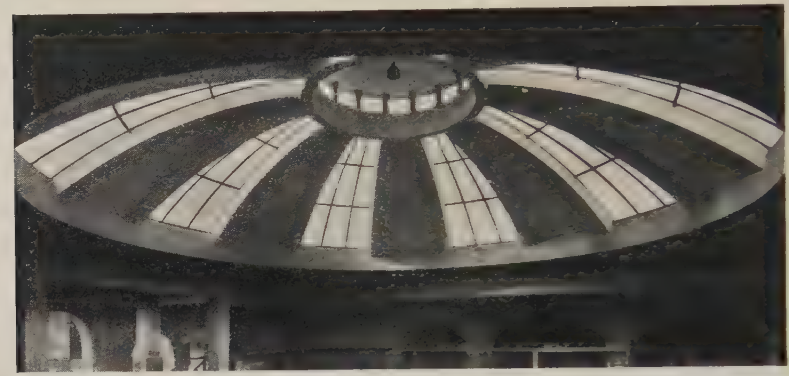


Fig. 230.—Reinforced Concrete Covering over Kingston Baths, Bath (Diameter—35 feet).

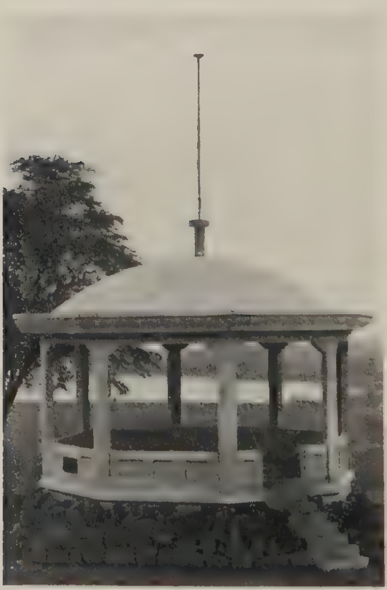


Fig. 231.—Reinforced Concrete Bandstand at Sutton-in-Ashfield.

In many cases the dome is required to support a heavy architectural feature at its summit, and the weight of this must be accurately estimated before commencing the design. There are usually two series of bars inserted to take the stresses, one in horizontal directions and the other in vertical corresponding to the circles of latitude and meridians on a globe. An annular section bounded by two parallels of latitude is in equilibrium, its weight being balanced by a peripheral tension in the section and by compressive stresses acting on its upper and lower faces. Stresses due to wind and temperature changes will modify the calculated section considerably, and it is seldom that a shell of less than 6-in. in thickness is used, whatever the theoretical thickness may be. Less thickness increases the cost of formwork and pouring the concrete.

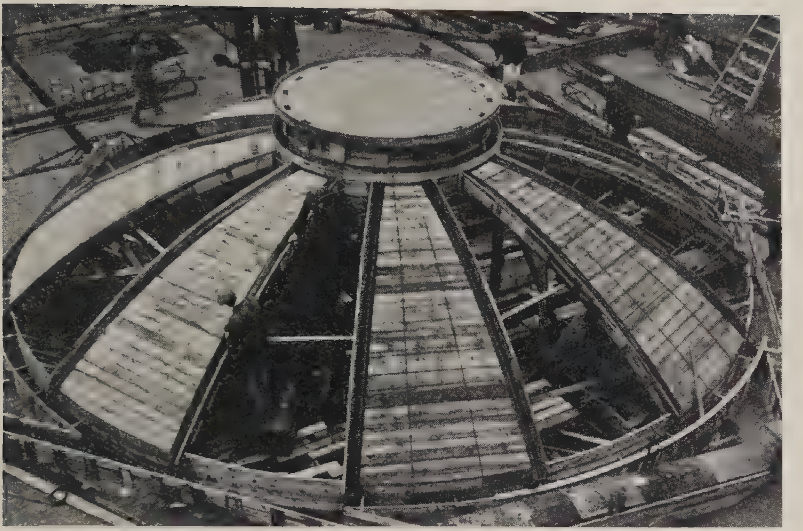


Fig. 232.—Roof over Kingston Baths, Bath, during construction.

The cost of the formwork is often prohibitive in dome construction unless there is a large number of small domes to be built, in which case the forms may be used over and over again.

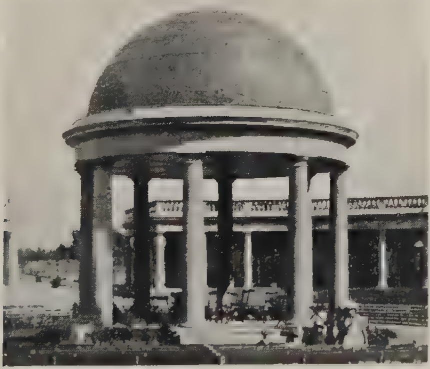


Fig. 233.—Reinforced Concrete Pavilion at Norwich.

Fig. 232 shows the construction of the large dome which is the principal feature of the flat reinforced concrete roof erected to cover the old Roman baths which were erected at Bath A.D. 54. The dome is fitted with glass lights, is 35 ft. wide at its base and about 10 ft. high. It is supported by beams which are monolithic with the ring-beam. The ribs consist of arched beams with spandrel slabs between.

Stands

Stands may be divided into two classes, with or without roofs. The latter are structurally a wide staircase with long treads and low risers.

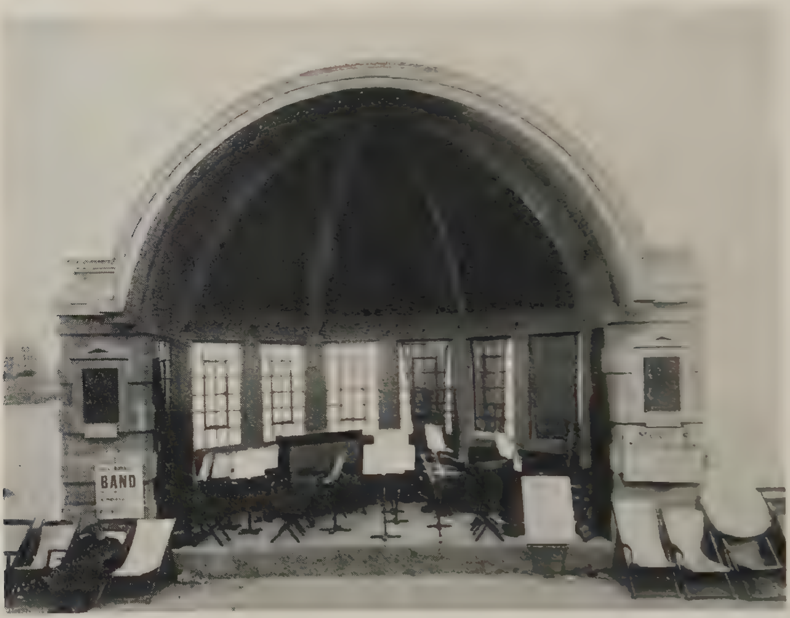


Fig. 234.—Reinforced Concrete Bandstand at Weston-super-Mare.

The risers may act as narrow beams spanning between sloping main girders supported on columns which increase in length from the front to the back of the stand or the steps may span (as bent slabs) in groups of four or more between secondary beams running parallel to the rows of seats and supported on main girders as before.

Roofed stands are easily constructed if columns are permissible, the loads from the roof being transmitted to the ground by the columns which pass down through the seating slab.

If obstruction of view by columns is not permitted it becomes necessary to cantilever the roof from a row of columns in the back of the stand. In

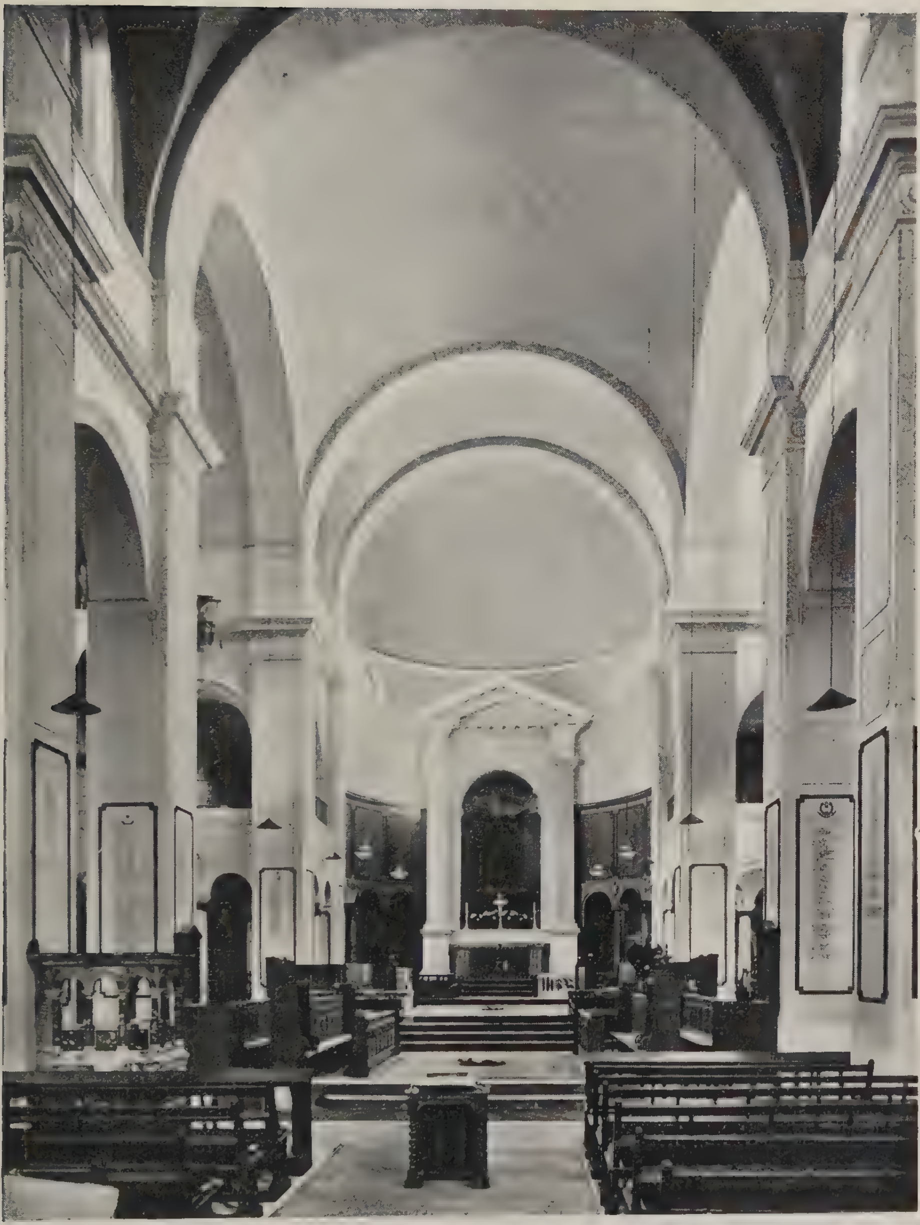


Fig. 235.—Sandhurst War Memorial Chapel: In Reinforced Concrete.

these cases the roof slab may span in the direction of the longitudinal axis of the stand and be supported by cantilever beams which are anchored down to the rear columns. Unless the roof may be loaded by spectators it is allowable to consider the live load on the slab as being of small magnitude such as would be caused, in Great Britain, by snow.

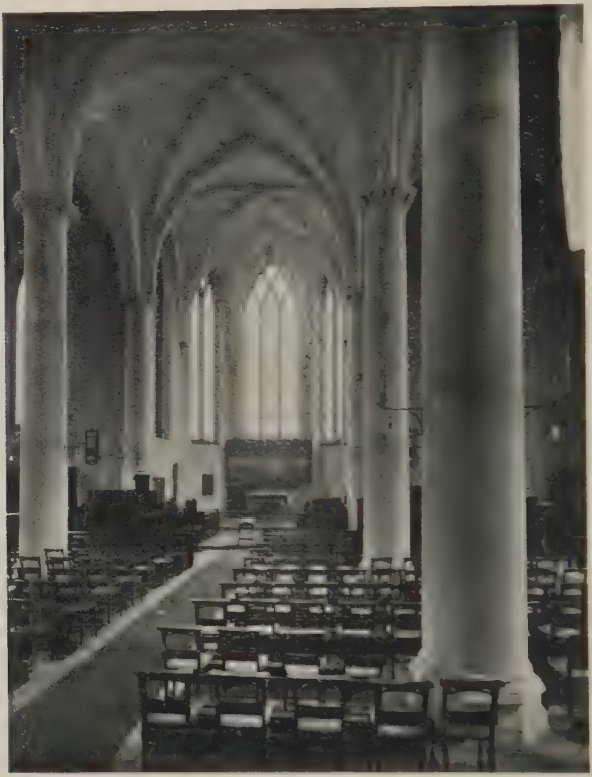


Fig. 236.—Rosyth Church: Reinforced Concrete Construction.

Uncovered stands for cricket and tennis grounds and aerodromes are illustrated in *Figs.* 239 to 241. A small race stand and a football stand with roofs are shown in *Figs.* 243 and 246. *Figs.* 242 and 245 are examples of roofed stands with cantilever beams. Other examples of stands are illustrated by *Figs.* 244, 246, 247 and 248.

Very large numbers of reinforced concrete stands have been erected on race-courses, cricket and football grounds, tennis courts, etc. Wembley Stadium, built completely in reinforced concrete, is probably the largest stand in the world.

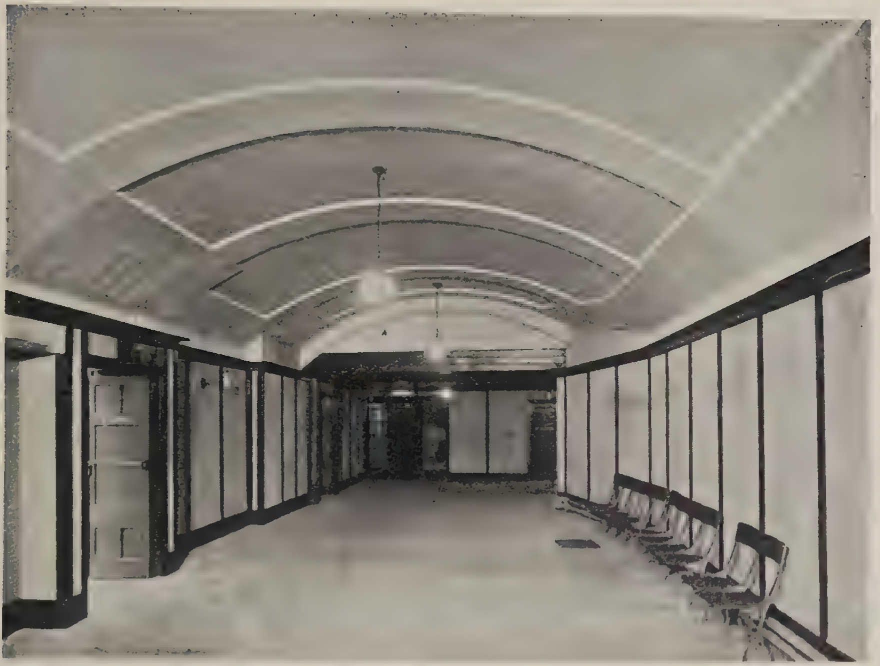


Fig. 237.—Vaulted Reinforced Concrete Ceiling at Accrington Picture Theatre.

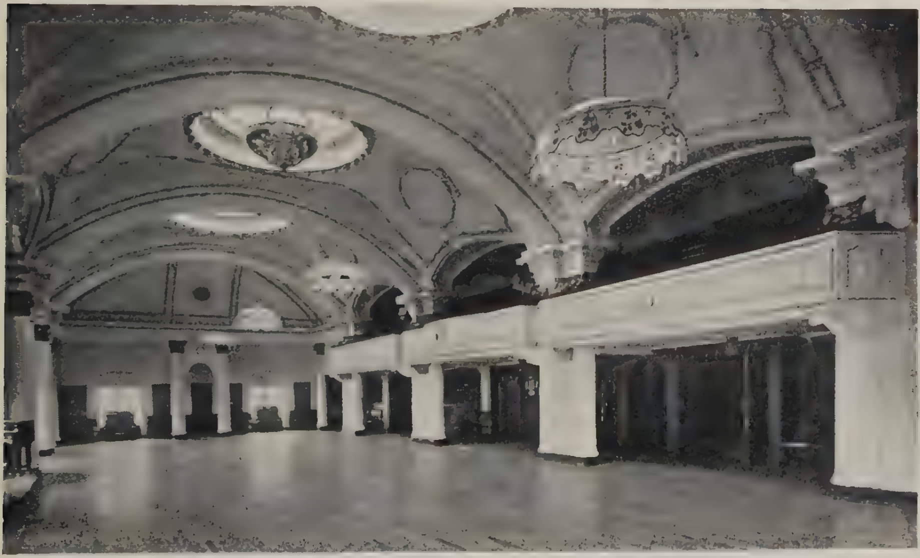


Fig. 238.—Reinforced Concrete Vaulted Ceiling at a Glasgow Restaurant.

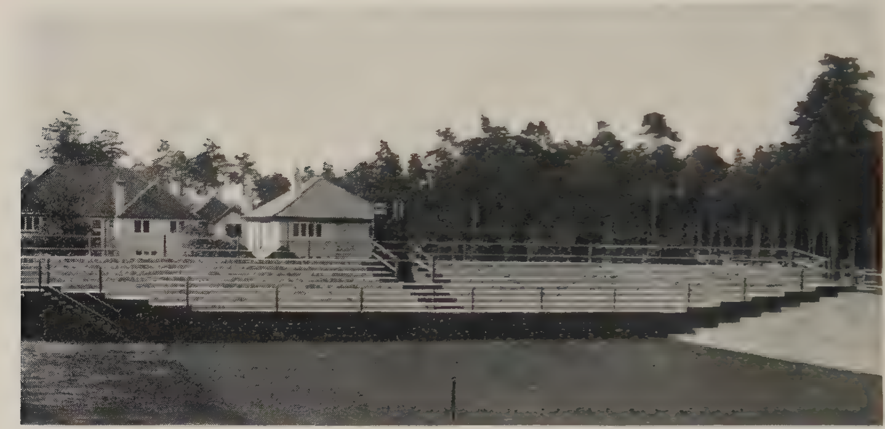


Fig. 239.—Reinforced Concrete Tennis Stands, Bournemouth.

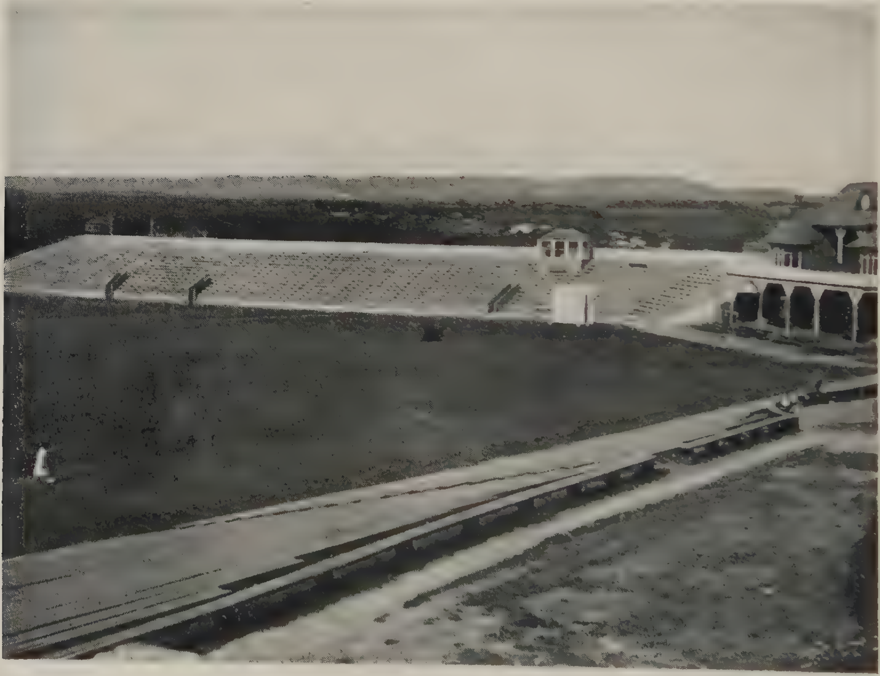


Fig. 240.—Reinforced Concrete Cricket Stand at Scarborough.

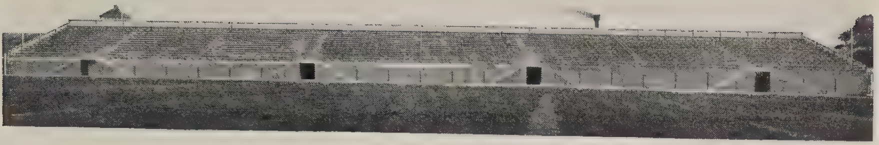


Fig. 241.—Reinforced Concrete Grandstand at Hendon Aerodrome.

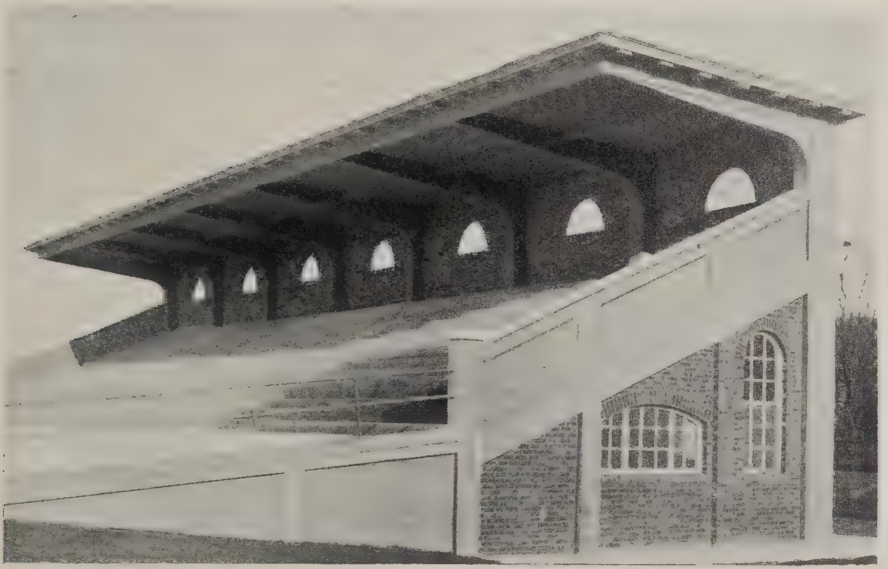


Fig. 242.—Reinforced Concrete Racecourse Stand, Thirsk.

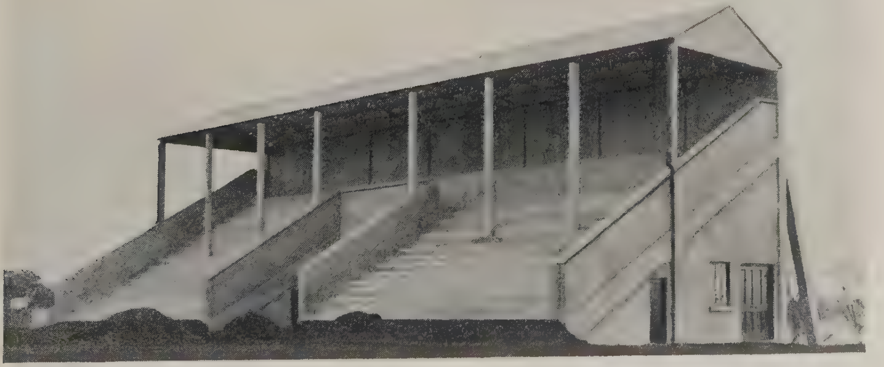


Fig. 243.—Reinforced Concrete Race Stand at Limerick.

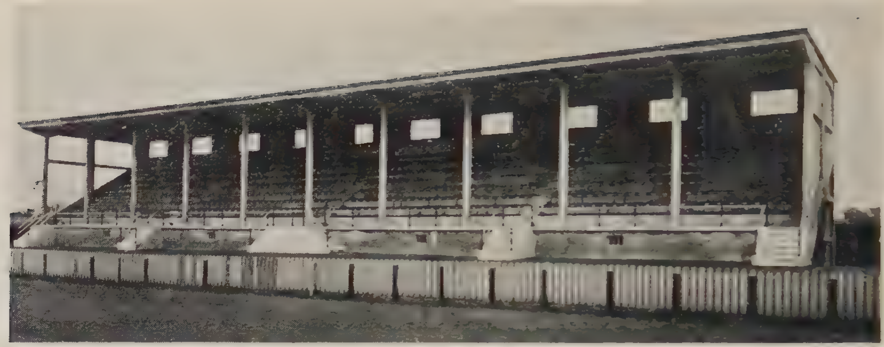


Fig. 244.—Reinforced Concrete Race Stand in Ireland.

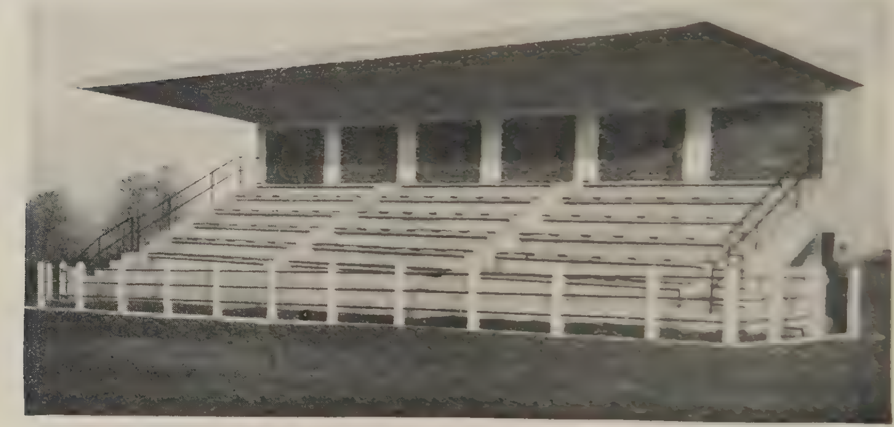


Fig. 245.—Reinforced Concrete Football Stand at Braintree.

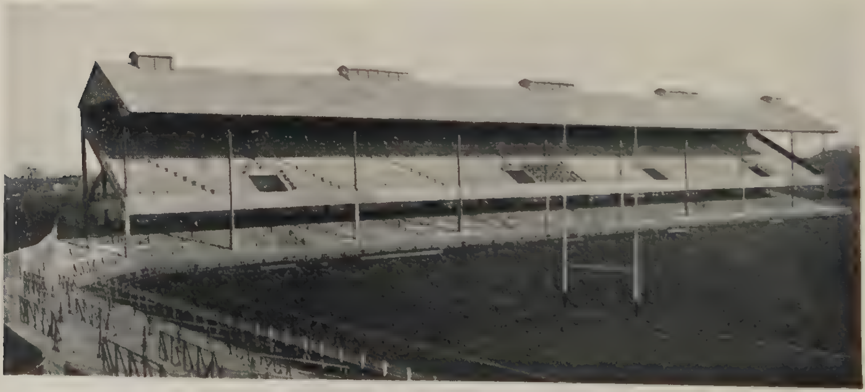


Fig. 246.—Reinforced Concrete Football Stand at Dublin.

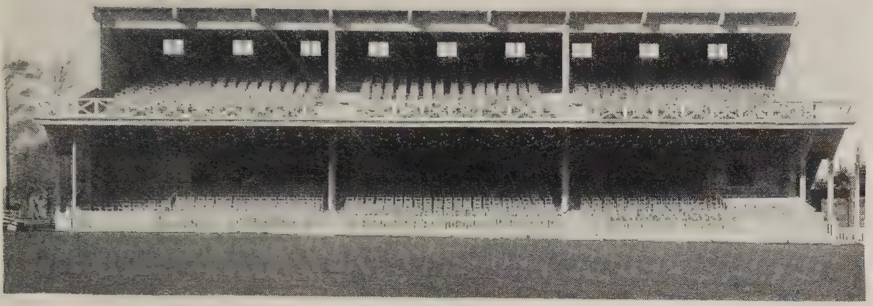


Fig. 247.—Reinforced Concrete Cricket Stand at Canterbury.

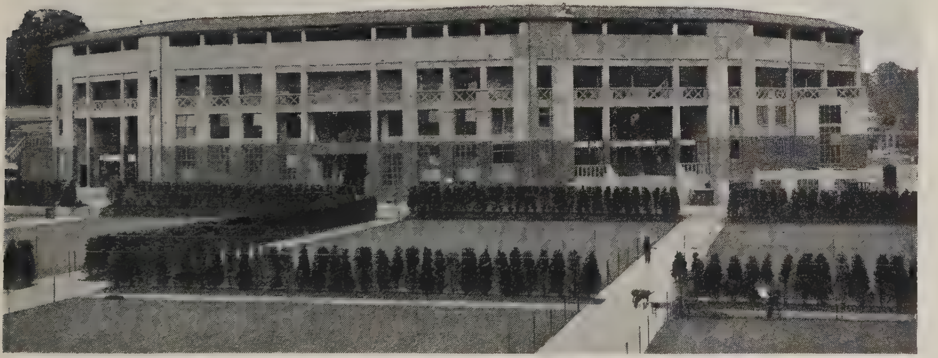


Fig. 248.—Reinforced Concrete Centre Court at the All-England Lawn Tennis Ground, Wimbledon.

Bridges

Reinforced concrete on account of its low first cost, its freedom from maintenance charges for painting and repairs and its structural adaptability to all shapes is the material par excellence for bridges. Since the year 1900, when the first reinforced concrete bridge was erected in Great Britain at Alton (Hants), about 2,000 bridges have been constructed in this material in this country, and during the last twenty years some very large spans have been completed. The three reinforced concrete arches over the Esk in Cumberland have each a span of 175 ft. while the recently opened bridge at Berwick includes an arch of 361 ft. 6 in. span. On the Continent still

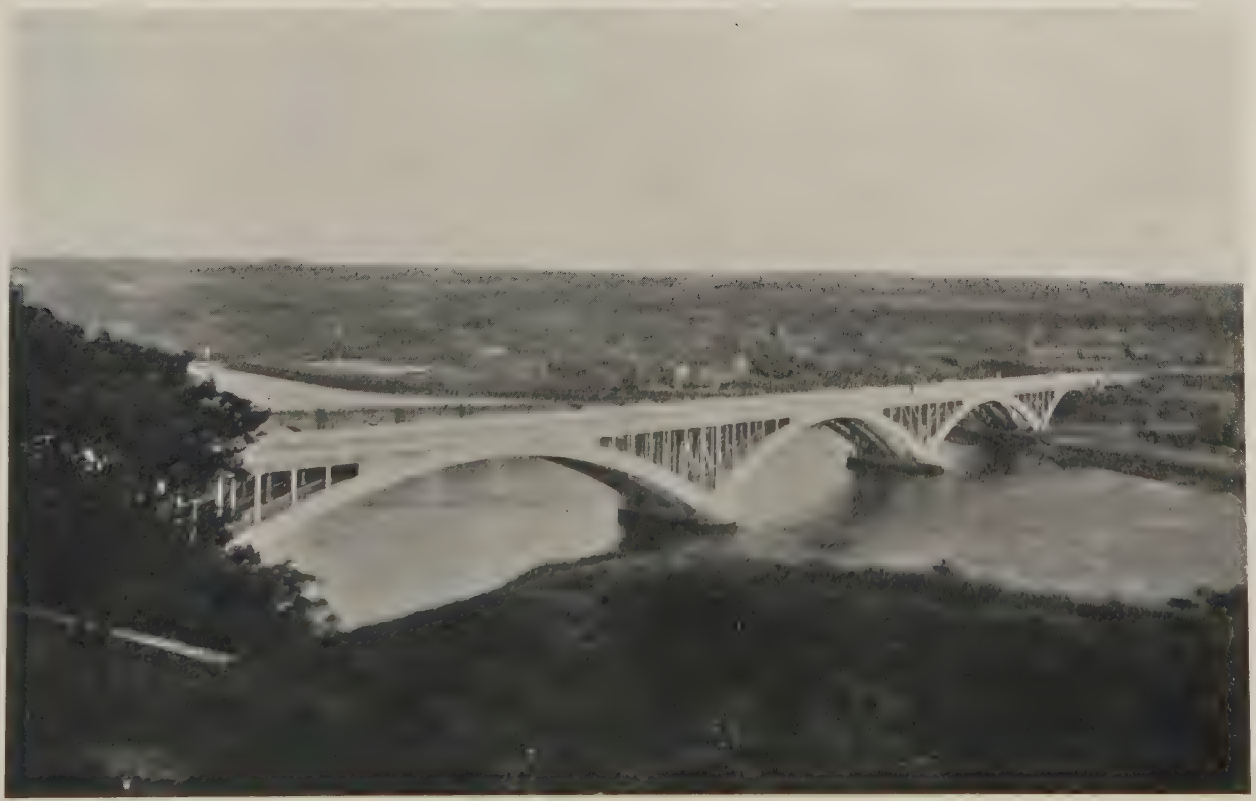


Fig. 249.—Reinforced Concrete Bridge at Berwick-on-Tweed.

[Total length 1,398 ft., including a viaduct forming the southern approach 192 ft. long; four arched spans 167 ft., 248 ft., 285 ft., and 361 ft. 6 in., and a northern approach viaduct 144 ft. 6 in. long.]

longer spans have been bridged in reinforced concrete; the Seine at St. Pierre du Vauvray is crossed by a reinforced concrete bridge 430 ft. in span, while the Plougastel bridge, over 3,930 ft. in length, includes three arches each of 590 ft. span.

It has frequently been argued by the opponents of reinforced concrete that the colour of the plain concrete is unpleasing to the eye, but the introduction of "Snowcrete" and "Colorcrete" and the use of selected aggregates, pre-cast facing and modern methods of surface finishing such as those described in Part III, have resulted in the production of work which is beyond such criticism.

Loading.—Footbridges (*Figs.* 250 and 251) are usually designed for a load of 100 lbs. per sq. ft. uniformly distributed all over the decking. In Great Britain the standard loading for road bridges is that of the Ministry of Transport, graphically shown in *Fig.* 252. This is sufficiently heavy to cover any probable increase in axle loads in years to come.

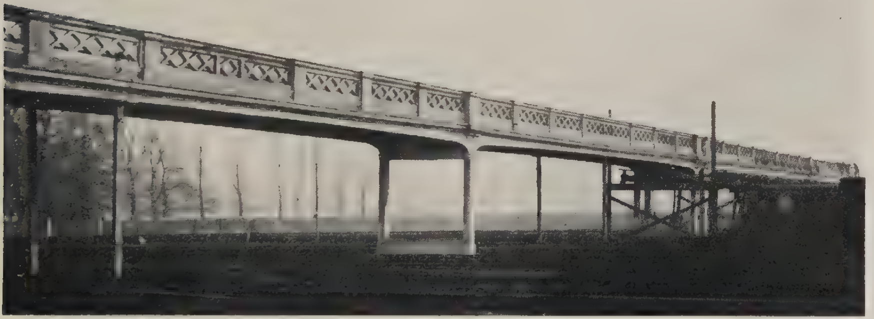


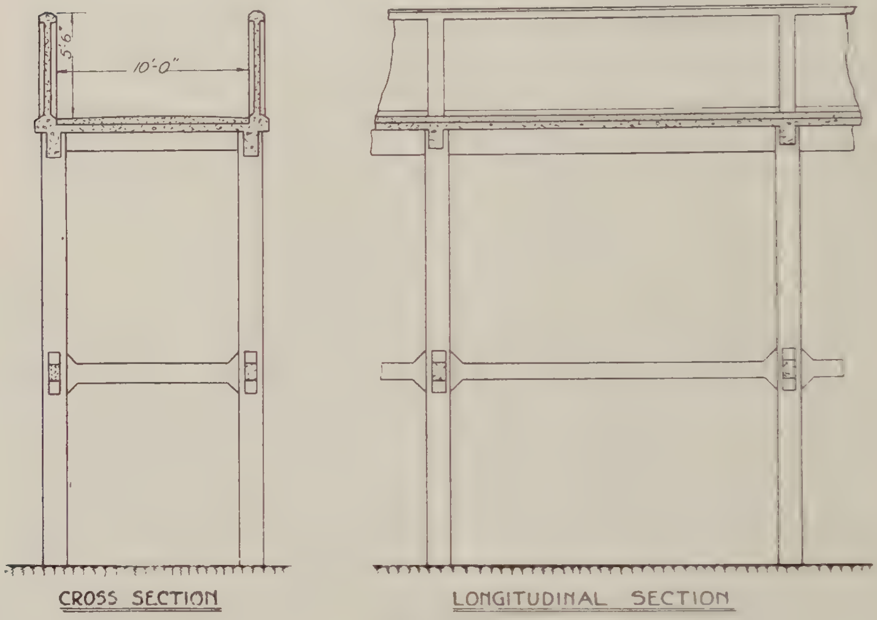
Fig. 250.—Reinforced Concrete Footbridge.

Reinforced concrete road bridges may be divided into five classes, namely, slab, deck girder, through girder, arch and cantilever bridges, any of which may be in single or continuous spans.

Slab Bridges.—Simple slabs are used abroad for spans up to 20 ft. to 24 ft., but in this country the usual limit is about 12 ft. above which the slab thickness required is considerable. The reinforcement of the slab is extremely simple, the main bars being arranged near the bottom of the slab with about 1-in. cover of concrete. At about one-fourth of the span from each end every alternate bar is generally bent up towards the top of the slab and there run on horizontally leaving sufficient steel in the bottom of the slab to resist the decreased bending moments near the supports.

The steel in the transverse direction acts as a distributor and is much lighter than that at right angles to it.

Slab bridges have been constructed of pre-cast members which require reinforcement to resist the stresses arising during handling or lifting them. Such members are cast hollow and may be manufactured very rapidly if rapid-hardening cement is used. In this way the time required for the construction of a bridge may be greatly reduced.



CROSS SECTION

LONGITUDINAL SECTION

Fig. 251.

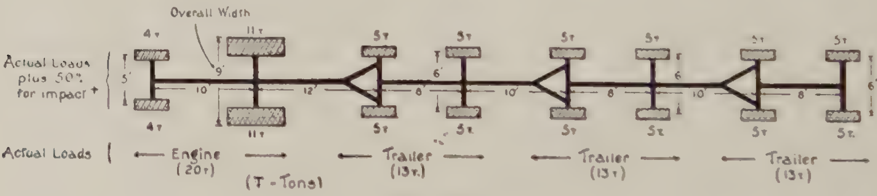

Overall Width
Actual Loads plus 50% for impact
4T
11T
5T
5T
5T
5T
5T
5T
9'
5'
10'
12'
6'
8'
10'
6
8
10'
8'
6'
4T
11T
5T
5T
5T
5T
5T
5T
Actual Loads
Engine (20T)
(T - Tons)
Trailer (13T)
Trailer (13T)
Trailer (13T)

Fig. 252.

Two kinds of supports are in general use, (*a*) the plain abutment with a sliding joint between the underside of the slab and the top of the abutment and (*b*) the abutment which is monolithic and continuous with the slab,

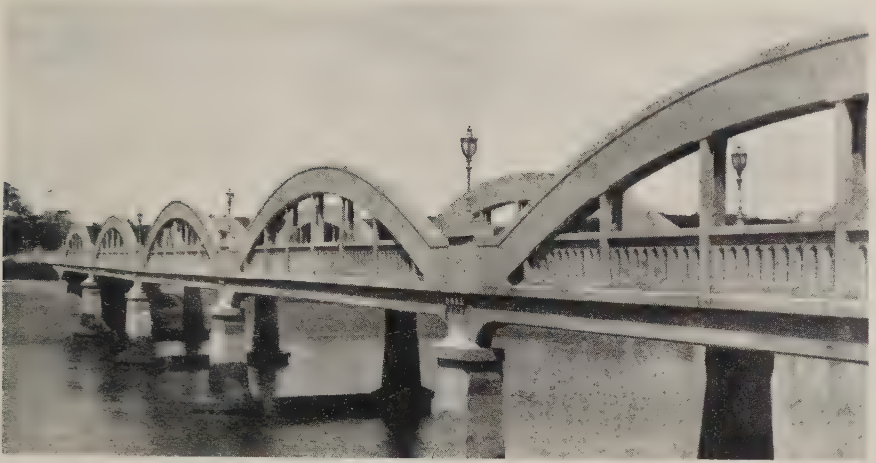


Fig. 253.—Reinforced Concrete Bridge at Kirkcudbright.

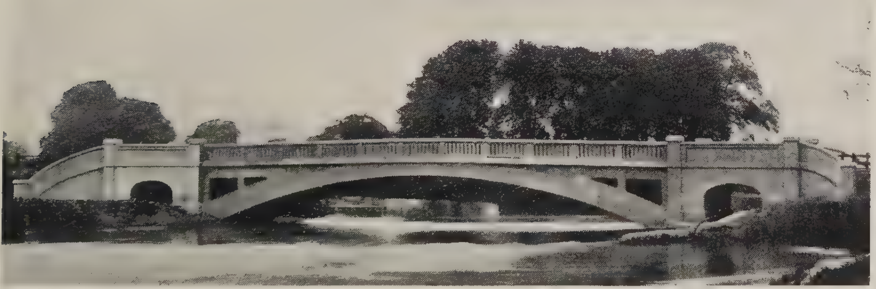


Fig. 254.—Reinforced Concrete Bridge at Allestree.

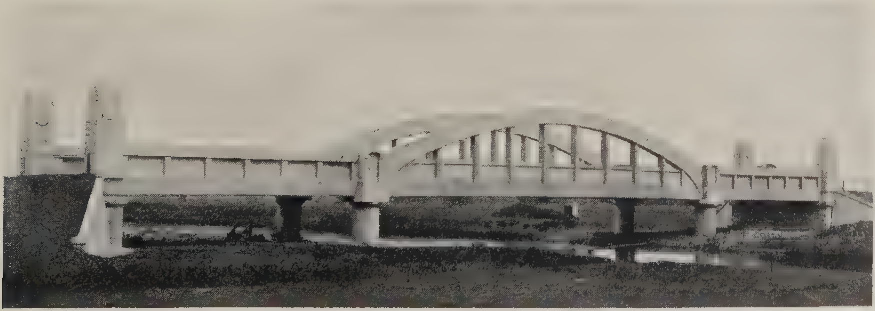


Fig. 255.—Reinforced Concrete Bridge at Dimmocks Cote, Cambridgeshire.

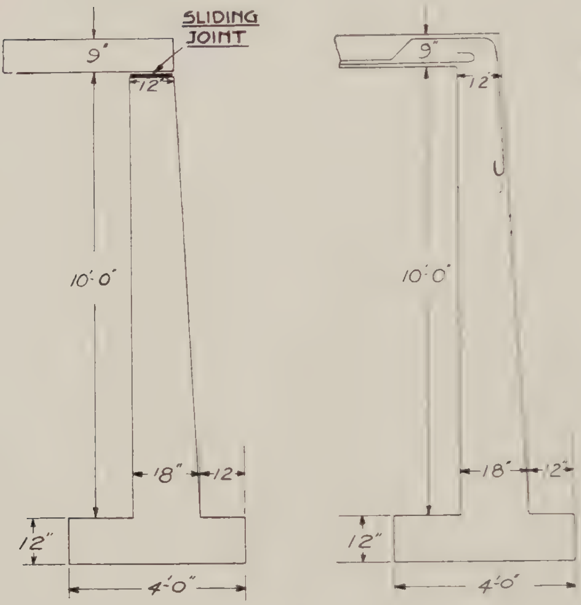

SLIDING JOINT
9"
12"
10'0"
18"
12
12"
4'0"
9"
12"
10'0"
18"
12"
12"
4'0"

Fig. 256.

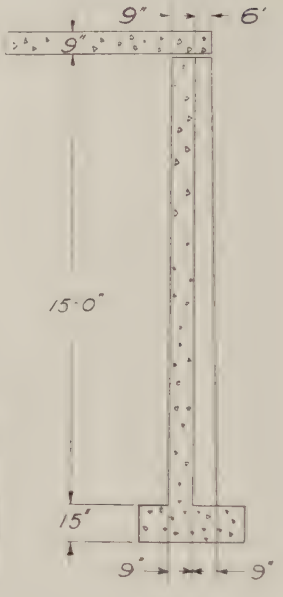

9"
6'
9"
15'0"
15'
9"
9"

Fig. 257.

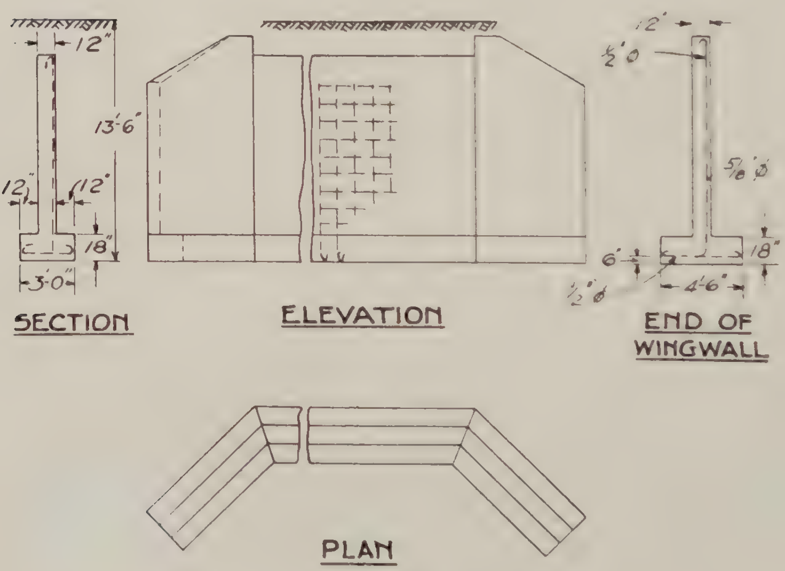

12"
13'6"
12"
12"
18"
3'0"
SECTION
ELEVATION
12"
½"∅
5/8"∅
18"
6"
½"∅
4'6"
END OF WINGWALL
PLAN

Fig. 258.

the whole being designed as a rigid frame (*Fig.* 256). With low abutments the wall is made to span in a vertical direction. High abutments are designed with pilasters on either front or back face, the wall slab spanning horizontally between these (*Fig.* 257). A layer of dry stone filling should be placed at the back of the abutment to provide for drainage.

Wing walls to retain the filling of the earthen approach banks are designed as independent retaining walls either straight or curved in plan. If in the former manner they may either be in the same straight line as the abutment or bent back (*Fig.* 258). A construction joint between wing wall and abutment prevents the formation of unsightly cracks. Such joints should be filled with bitumen.

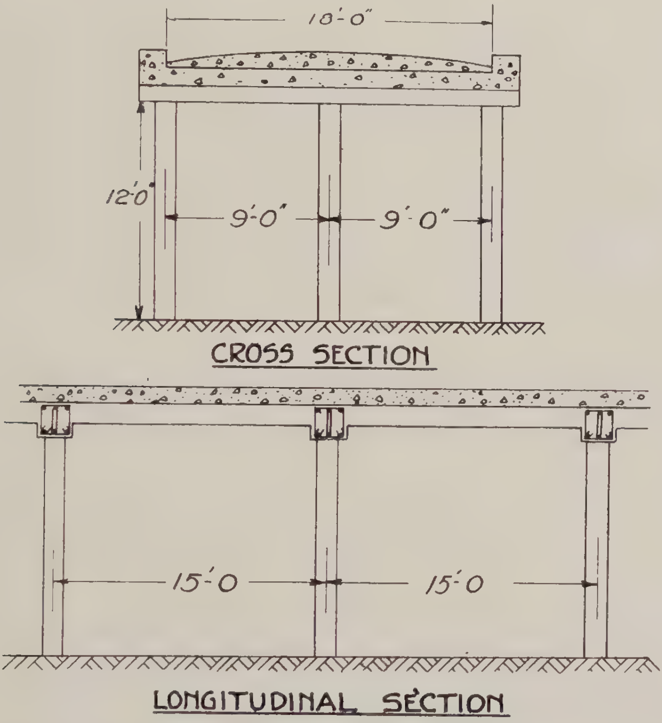


Fig. 259.

The simplest type of continuous slab bridge comprises a slab resting on a pile cap (*Fig.* 259) forming the top of a piled trestle, a development of the old-fashioned timber trestle bridge for railways which is still in use in new countries.

Deck Girder Bridges.—In deck girder bridges the slab generally spans across the width of the bridge and acts as compression flange for the girders beneath. This type is commonly used up to 60 ft. in span. *Fig.* 260 is an outline section in the direction of the span of a deck girder bridge in which the slab is supported on all four sides. In this example the girders and pilasters of the abutment are combined to act as a rigid frame. The footpaths may be supported on cantilever brackets or between the outer main deck girder and the parapet girder. It is usual practice to provide a

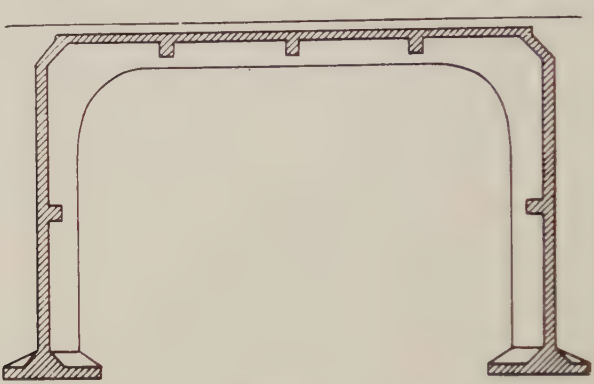


Fig. 260.

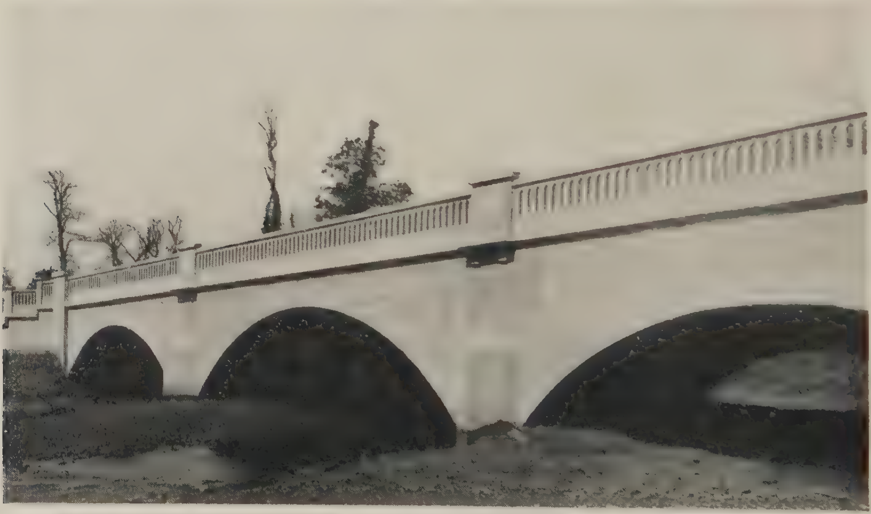


Fig. 261.—Reinforced Concrete Bridge on Newport-Cardiff Road.

pipe trough below the footpath, which may be of pre-cast slabs in order to give easy access to the pipes and cables. In continuous deck-girder bridges it is necessary to increase the depth of the main girders or reinforce them in compression near the piers where the slab no longer acts as compression flange. In some cases a special compression flange is inserted connecting the under surfaces of the beams near the piers. Due to the action of rolling loads steel is required at the top of the main beams to resist the negative moments in one span owing to its neighbour being under load.

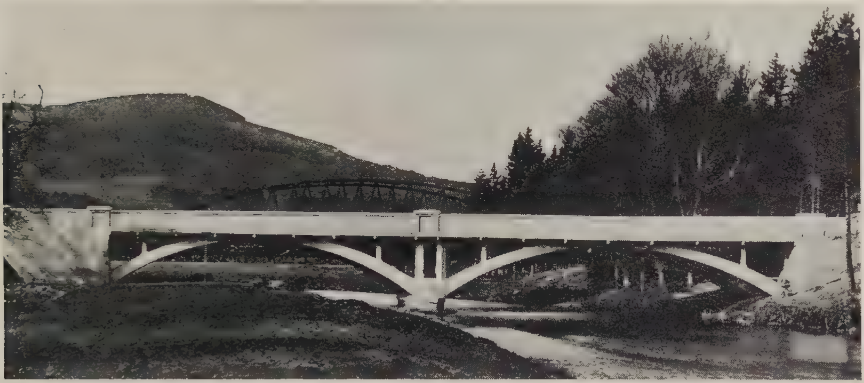


Fig. 262.—Crownhead Bridge (in Reinforced Concrete).

The abutments of such bridges are generally separate structures (not monolithic with the girders) and are provided with pilasters on which roller or rocker bearings are supported to carry the ends of the main girders. In long bridges of many spans intermediate piers often consist of "pendulum" columns designed to resist the stresses due to longitudinal movement. In rivers subject to heavy floods bringing down débris a cutwater is an essential feature of all piers for bridges and is often constructed with granite

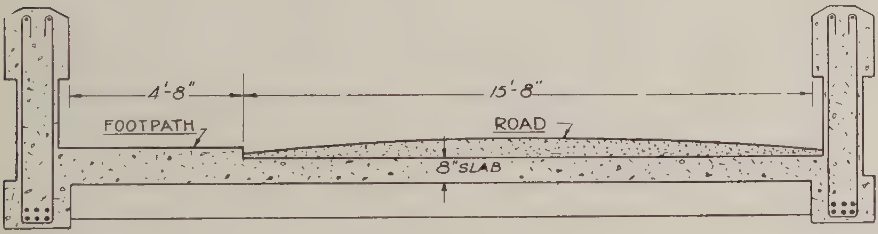


Fig. 263.

facing. It should be fitted with a steel angle-nosing if there is any danger of floating masses of ice coming in contact with the pier.

Where headroom is very limited the "through" bridge (*Fig.* 263) has many advantages over the deck-girder type. It is, however, seldom built as a continuous structure.

Cantilever Bridges.—When it is necessary to span a large and two smaller side openings a cantilever bridge with supported middle span often proves economical. The middle span rests on cast-steel bearings the lower portions of which are supported at the ends of the cantilevers. Special compression flanges may be introduced on the underside of the cantilever by providing a reinforced concrete slab spanning between the main ribs.

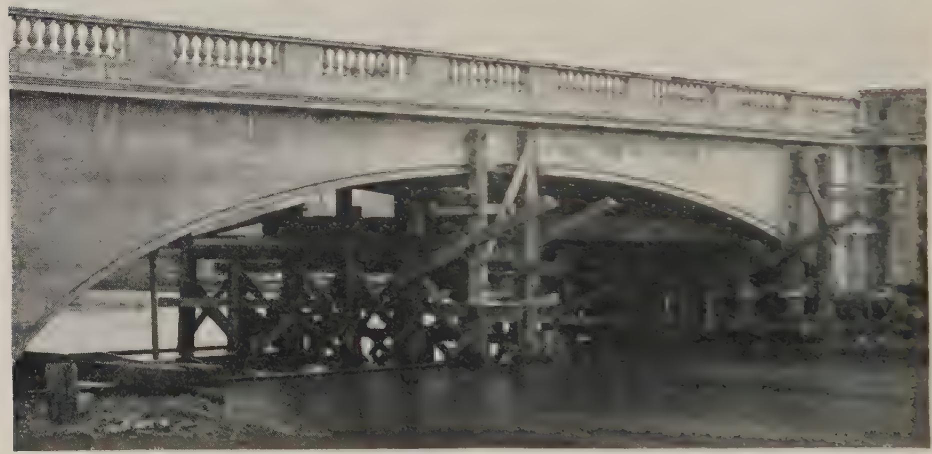


Fig. 264.—Albert Bridge, Old Windsor: During Construction.

Design and Construction.—For simple spans over 80 ft. the arch is generally the cheapest form of reinforced concrete bridge, especially if good foundations are available and the rise is not very limited. Arches with fixed ends are somewhat difficult to design and if there is any uncertainty about the degree of fixation obtainable it is advisable to provide hinges which may be either two or three in number. With three hinges the arch is statically determinate and the calculations are quite easily made, but if only two hinges are inserted the work required in design is troublesome unless the form of the arch is parabolic. This shape however is not altogether pleasing to the eye. A method of constructing an arch which appears to be elliptical is shown in *Fig.* 264. In this example the parabolic arch is concealed by a screen wall of elliptical elevation. Reinforced concrete arches may consist of either a plain arch sheet supporting the road slab through the intermediary of spandrel walls, or columns and beams, or of a series of longitudinal parallel ribs connected together by a reinforced concrete slab on which columns or walls are built to support the

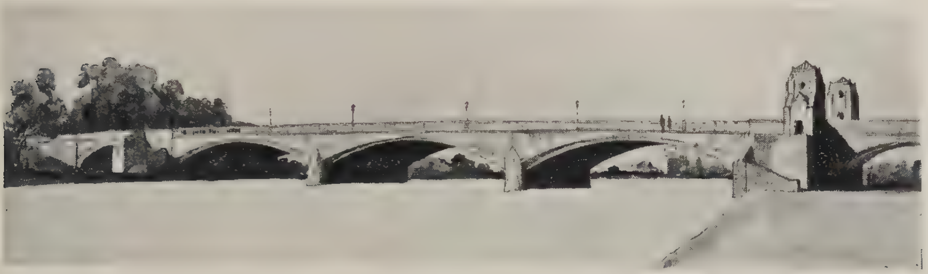


Fig. 265.—Reinforced Concrete Bridge to be erected over the Thames at Richmond.

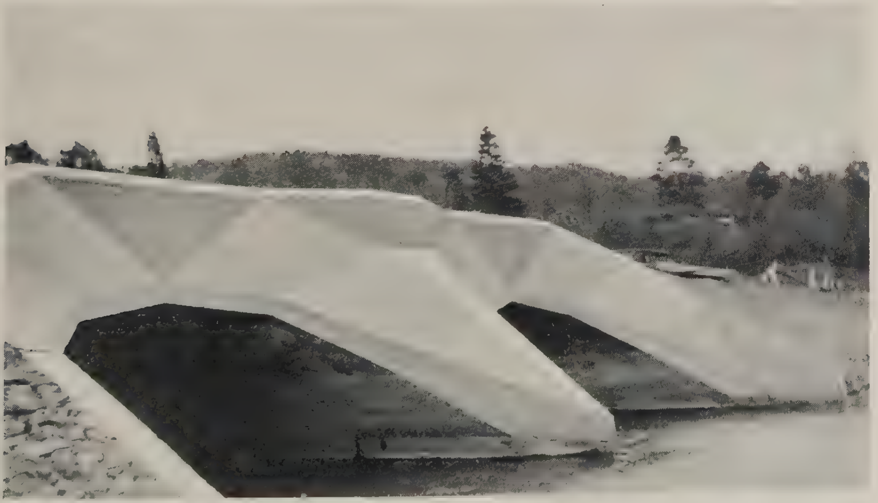


Fig. 266.—Reinforced Concrete Bridge at Lock Alvie.

decking. The space between the extrados of the arch and the deck slab may be filled with earth. Arches with open spandrels are relatively more expensive in formwork but do not require such a heavy arch-sheet as the closed type.

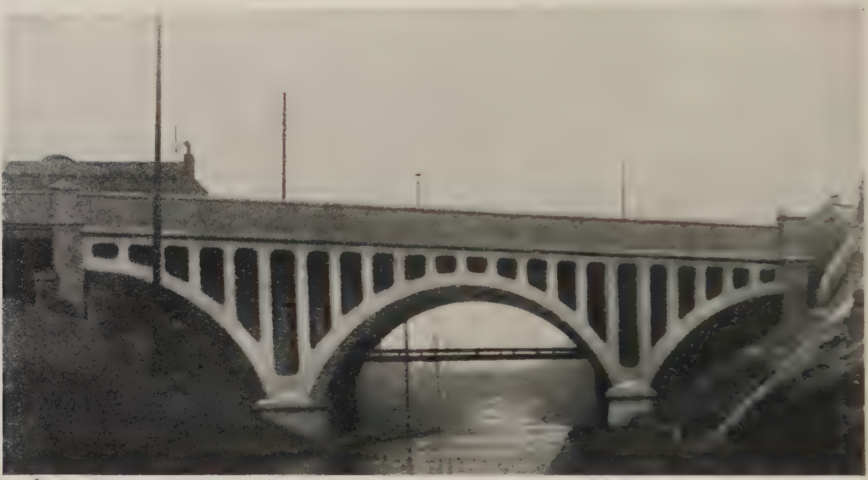


Fig. 267.—Spon Lane Bridge Widening in Reinforced Concrete.

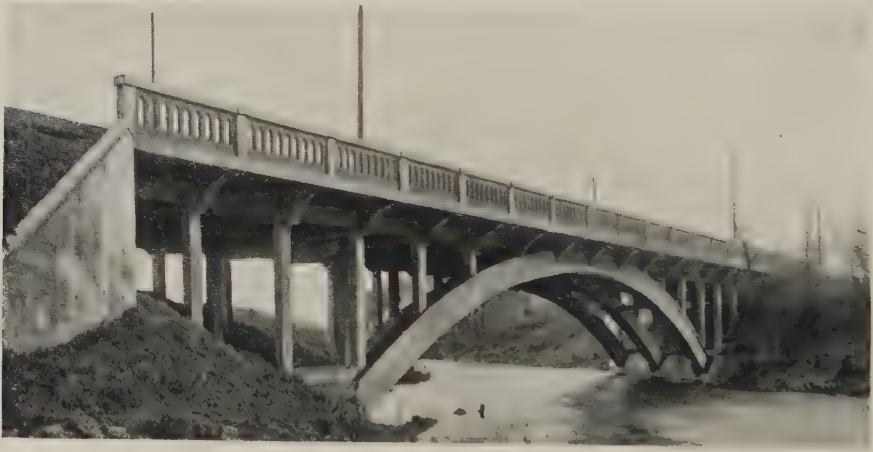


Fig. 268.—Reinforced Concrete Bridge at Larbert.

Hinges need not be permanent, in fact it is becoming usual to employ a type of hinge which really acts as such only during the construction of the arch and is later concreted in. The discussion of the various types of hinges is however outside the scope of this book. On the Continent cast iron has been used as reinforcement for arches of large span.

Somewhat akin to the arch is the bowstring-girder, a number of which have been constructed in reinforced concrete, the roadway slab being suspended by reinforced concrete members from the main arch ribs.

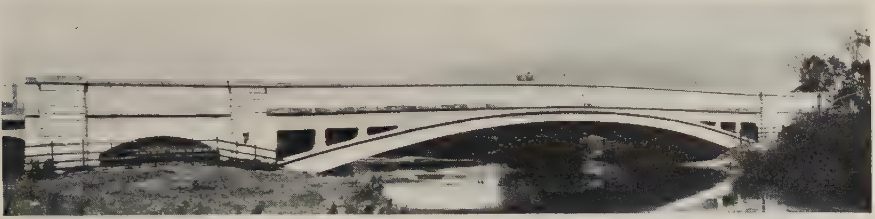


Fig. 269.—Reinforced Concrete Bridge at Egginton.

Footbridges of narrow widths are generally constructed with a slab spanning across the width and supported on longitudinal beams below the slab. In this way the slab acts as compression flange for the ell-beams below it. For long spans where as in railway-yards headroom is limited, the slab either spans directly between the bottom flanges of the parapet girders or between cross-girders supported by the latter. It is not unusual for the elevation of the parapet girders to be cranked as in *Fig.* 271, between the landing at the top of the steps and the level of the main slab.

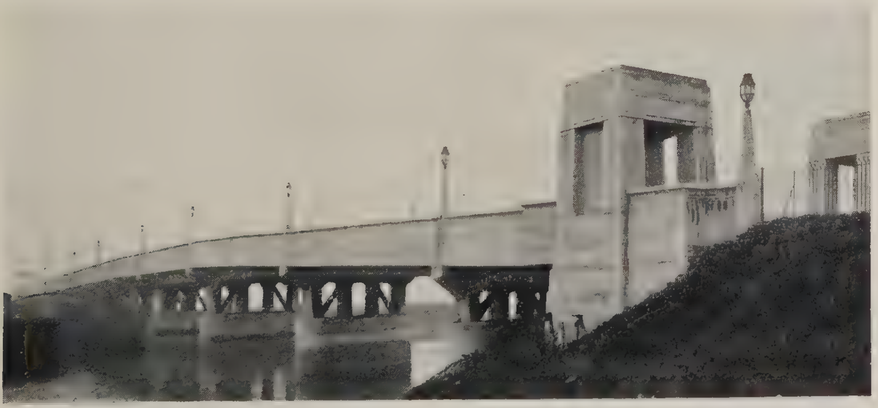


Fig. 270.—Reinforced Concrete Bridge on the East Ham and Barking By-Pass Road.

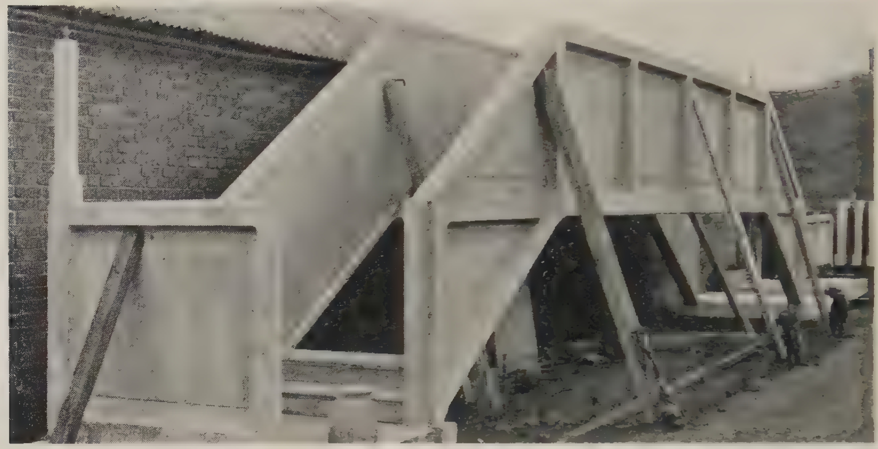


Fig. 271.—Pre-Cast Concrete Bridge Sections as made by Southern Railway Company.

Intermediate piers of multiple span bridges are founded on mass concrete, reinforced concrete slabs or on piles or cylinders if good-bearing strata are not found at a reasonable depth below the surface. The first two types of foundations are constructed by excavating in a cofferdam formed of braced

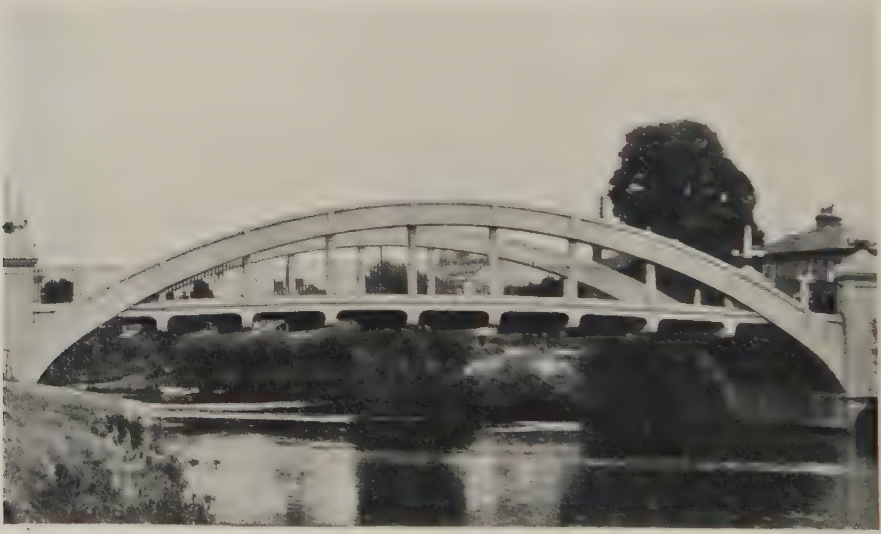


Fig. 272.—Reinforced Concrete Bridge at Evesham.

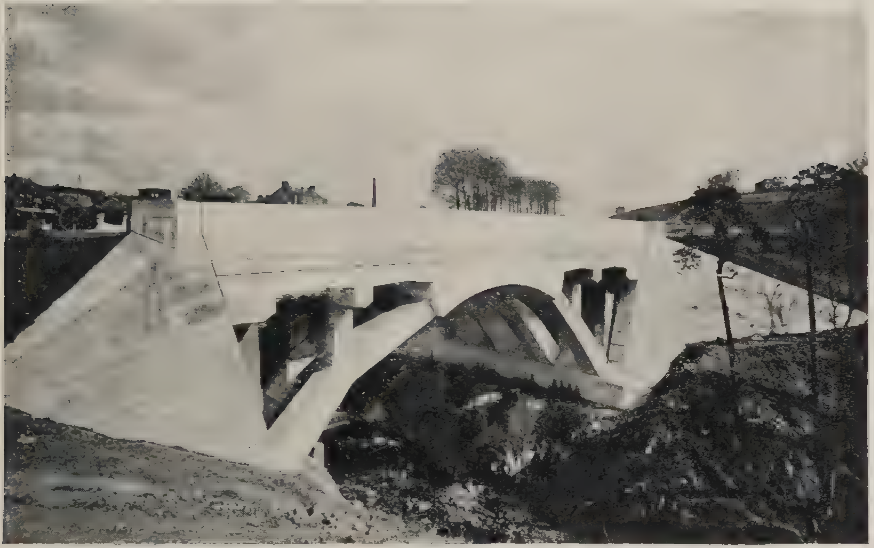


Fig. 273.—Reinforced Concrete Bridge at Duntocher.

sheet-piling which is withdrawn after the completion of the pier to a level above that of the river water. Cylinder foundations are sunk by compressed air until a depth is reached at which the friction on the sides of the cylinders is sufficient to carry the load with the requisite factor of safety. In some cases reinforced concrete piles are driven from a staging or barge

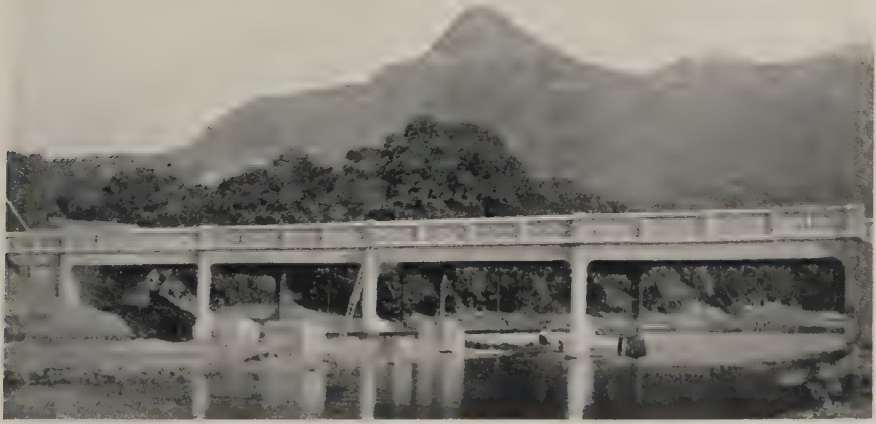


Fig. 274.—Reinforced Concrete Bridge at Ballachulish.

so that their heads project above water-level. Cylinders of pre-cast reinforced concrete are then lowered over these piles and supported on a suitable bed previously prepared by a diver. The work is completed by filling the cylinders with mass concrete.

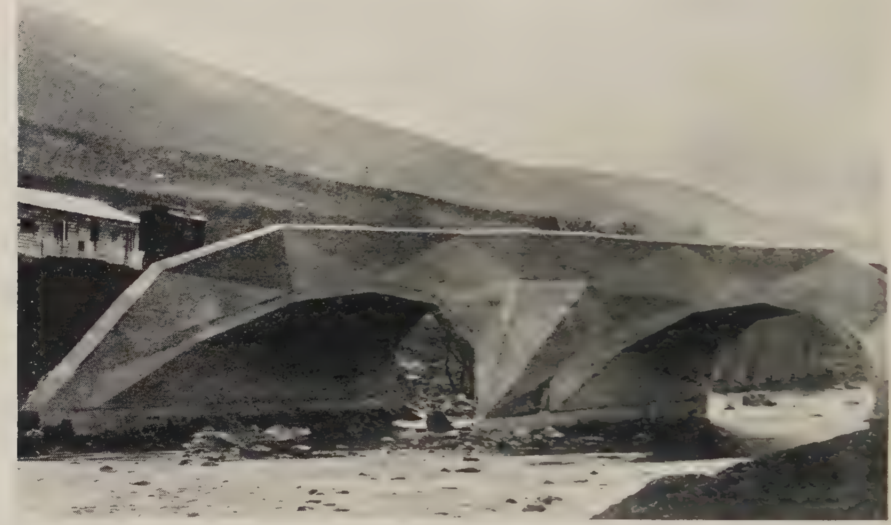


Fig. 275.—Reinforced Concrete Bridge at Crubenmore.

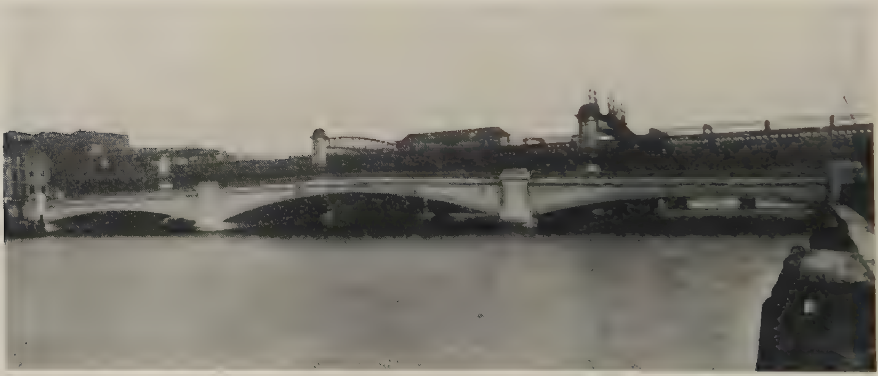


Fig. 276.—King George V Bridge, Glasgow : A Reinforced Concrete Structure faced with Stone.

In other cases it has been found necessary to build the pier on reinforced concrete caissons (*Fig.* 277)—box-like structures floated to the site, filled

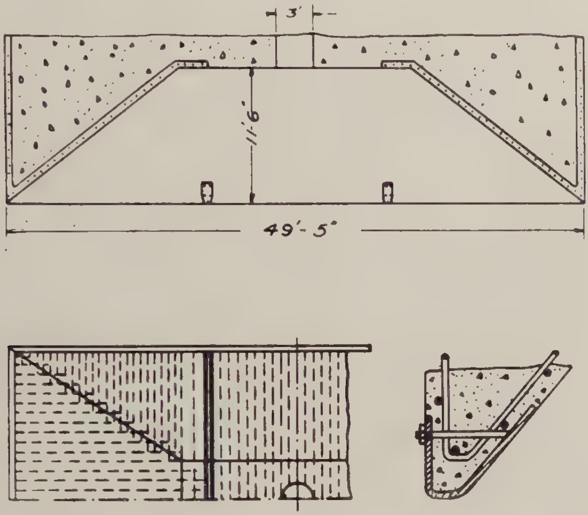


Fig. 277.

with water and sunk in position by excavating from inside under compressed air.

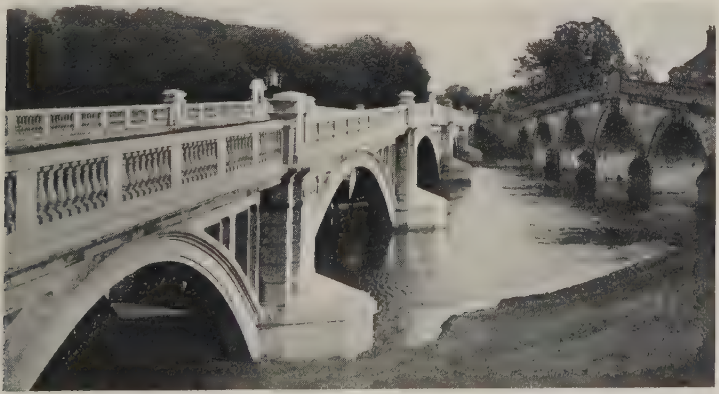


Fig. 278.—Reinforced Concrete Bridge at Atcham, Shropshire.

Formwork.—Owing to the simplicity of the shuttering required for simple slab spans these are more economical than the deck girder type for even longer spans than are commonly used in this country. The type of staging required depends on the nature of the ground to be bridged over and the clearance to be provided.

Girder bridges forms may be supported by posts or cribwork from the ground where this is possible. If, however, piling is required the supports become expensive and over railway tracks a series of rolled steel joists may be used to span between the abutments and support the beam bottoms.

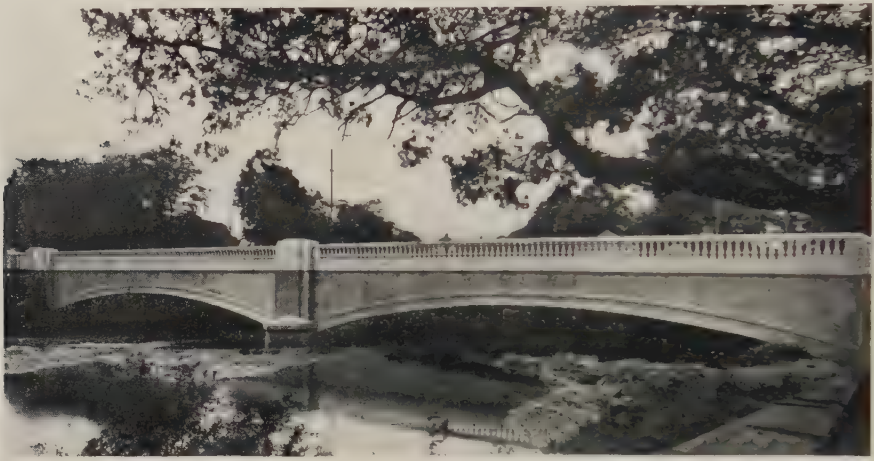


Fig. 279.—Reinforced Concrete Bridge at Glasgow.

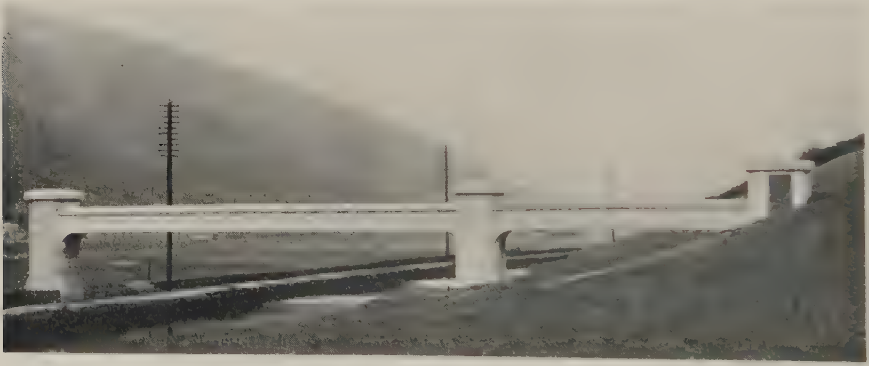


Fig. 280.—Reinforced Concrete Pipe Bridge at Rochdale.

For long spans second-hand lattice girders are often used under the forms, but if the headroom is limited the beam boxes may be hung by steel U-bolts passing through the flanges of the steel girders. Where clearance

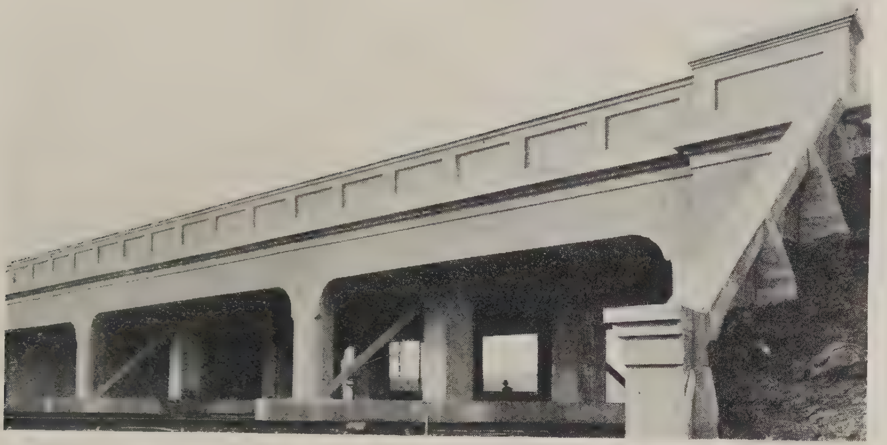


Fig. 281.—Reinforced Concrete Road Bridge.

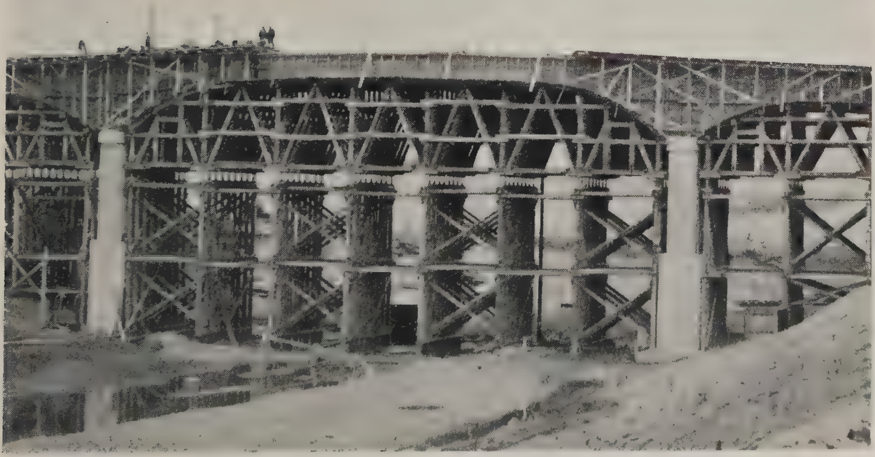


Fig. 282.—Reinforced Concrete Bridge in connection with the Shannon Hydro-Electric Scheme.

below is not required the forms may be carried by posts resting on concrete or timber mud-sills if the bearing capacity of the ground is sufficiently high.

The upper ends of the scaffolding for girder bridges and arches must be fitted with some kind of device for lowering the centres. Formerly sand-boxes were used, but these have lately been replaced by hardwood wedges or better still by jacks. By using the latter the whole centre may be lowered as a unit if the gang is properly organised.

The thicknesses required for slab or girder forms are 1 in. to 1½ in. for the slabs, 1¼ in. or 1½ in. for beam sides and 2 in. for beam bottoms. Particular care must be taken that the deflection of the forms is not excessive and the beam bottoms should be cambered at the rate of 1 in 30 else the beams will appear to sag when the shuttering is removed.

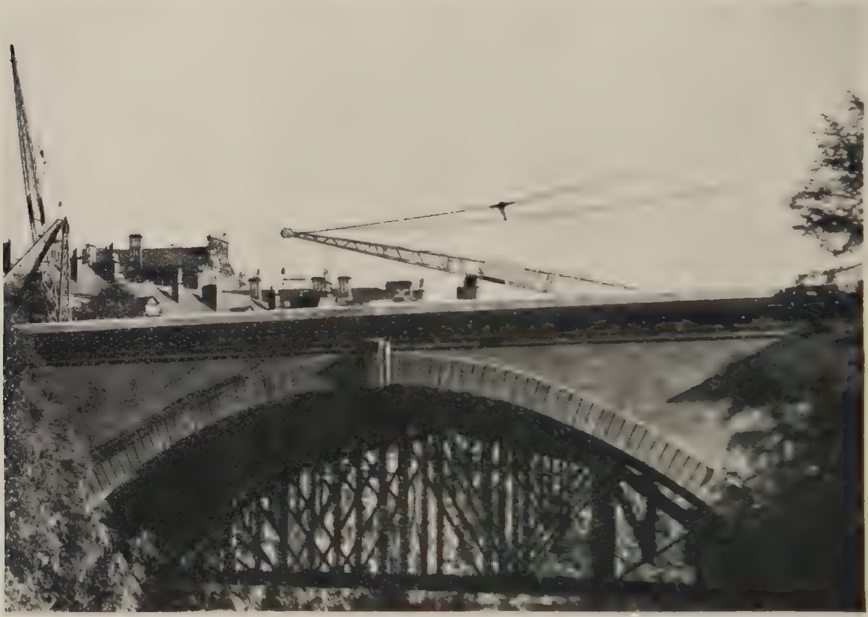


Fig. 283.—Reinforced Concrete Bridge at Glasgow.

Arch centering (*Fig.* 283) is supported in a similar manner to that used for girder bridges. The centre itself is built up from 1½-in. or 2-in. lagging nailed to stringers whose upper surfaces are curved to the outline of the arch intrados. Special packing pieces are required between the under surfaces of the stringers and the top of the posts.

The spacing of the posts supporting the stringers depends on the scantlings of the latter since their deflection must not be too great. Care must be used to ensure that the posts are braced both longitudinally and in a direction transverse to the bridge and a wind pressure of at least 40 lbs. per sq. ft. should be allowed for.

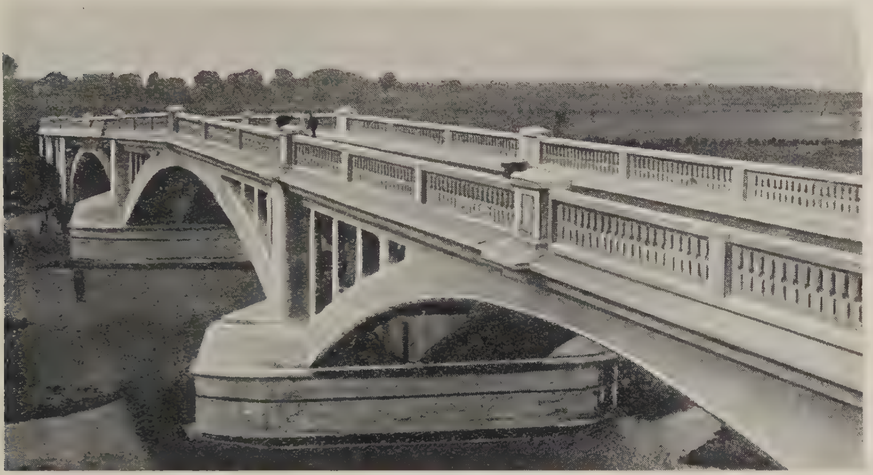


Fig. 284.—Reinforced Concrete Bridge in Cumberland.

Formwork for piers and abutments is best constructed in built-up panels of $1\frac{1}{4}$-in. timber, the sizes of the panels corresponding with the facilities for handling them and the lifts required in concreting. Bent steel bars may be cast in the concrete to hold the wire-ties passing round the studs

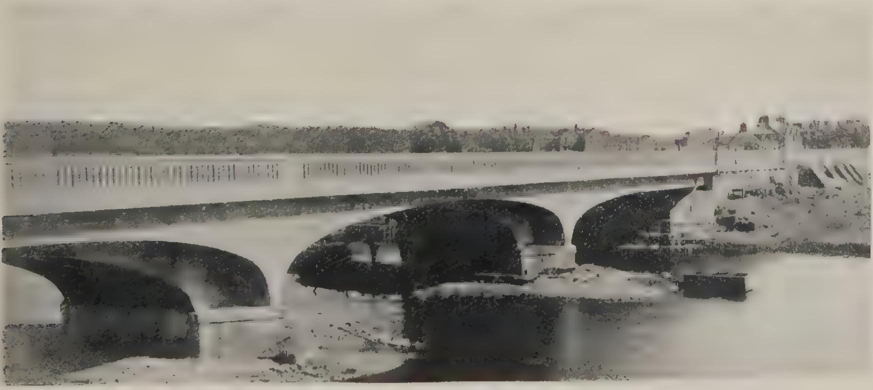


Fig. 285.—Reinforced Concrete Bridge over the River Don.

supporting the panels. If the height of the forms is small they may be braced (from the outside) by inclined struts.

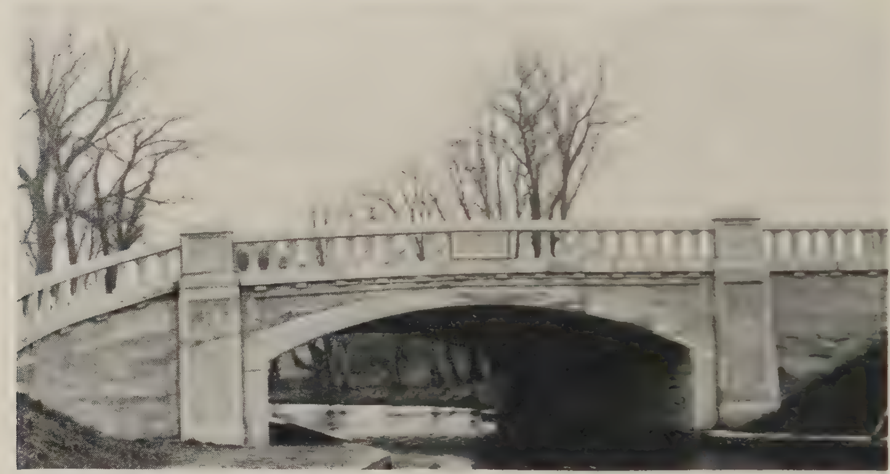


Fig. 286.—Reinforced Concrete Bridge at Bolton-le-Sands.

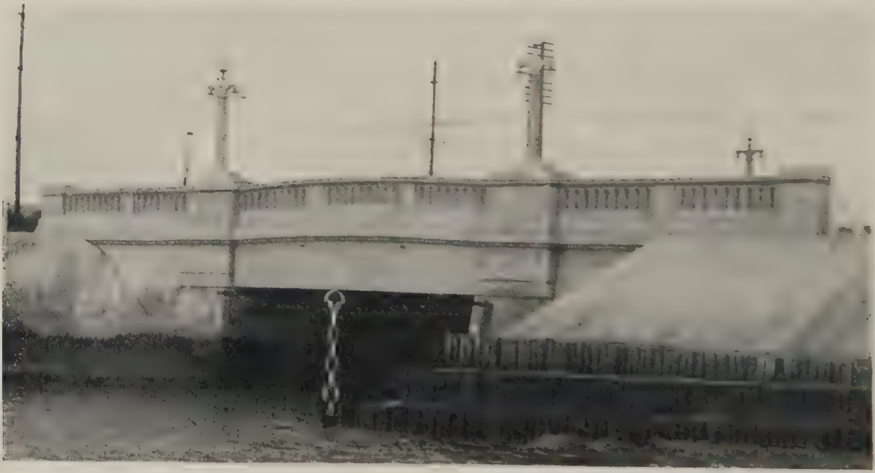


Fig. 287.—Reinforced Concrete Bridge at Portsbridge.

Concreting.—Rapid-hardening Portland cement is now used on bridge work since the time required before forms may be stripped is greatly reduced and so the bridges may be finished in much less time than if the concrete were mixed with the ordinary brands of Portland cement. Another reason for the adoption of the rapid-hardening brands in England is that the Ministry of Transport allows the working stresses to be increased by 25 per cent., thus permitting a saving in materials.

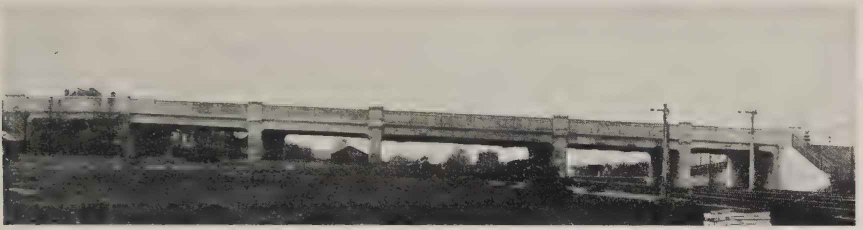


Fig. 288.—Reinforced Concrete Bridge at Cheam.

Ordinary slab or girder bridges are concreted in a similar manner to that already described as applicable to floors. Some specifications demand continuous pouring so that there shall not be any construction joints between the slab and the girder ribs.

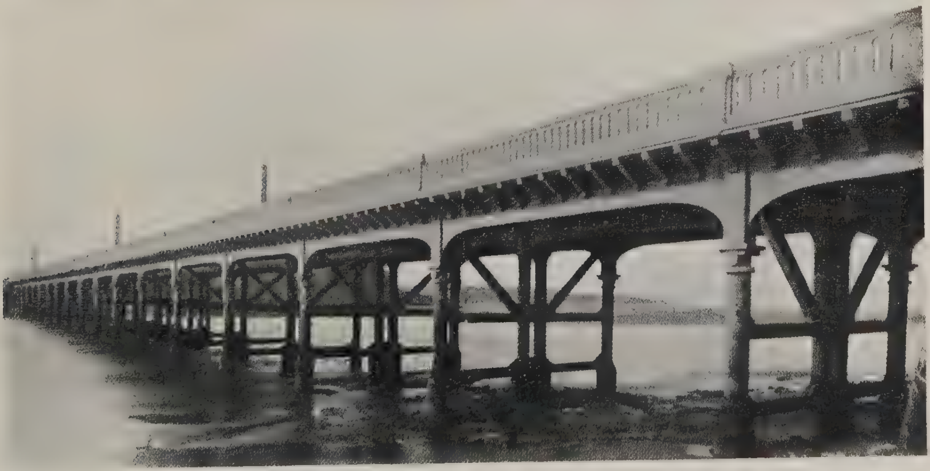


Fig. 289.—Reinforced Concrete Bridge at Loughor (720 ft. long by 35 ft. between Parapets).

In small arched bridges the concreting may be carried out in strips sufficiently wide to allow of each strip being done during one shift. It is essential to carry out the concreting from both abutments towards the centre of the span in order to prevent the centre being unsymmetrically

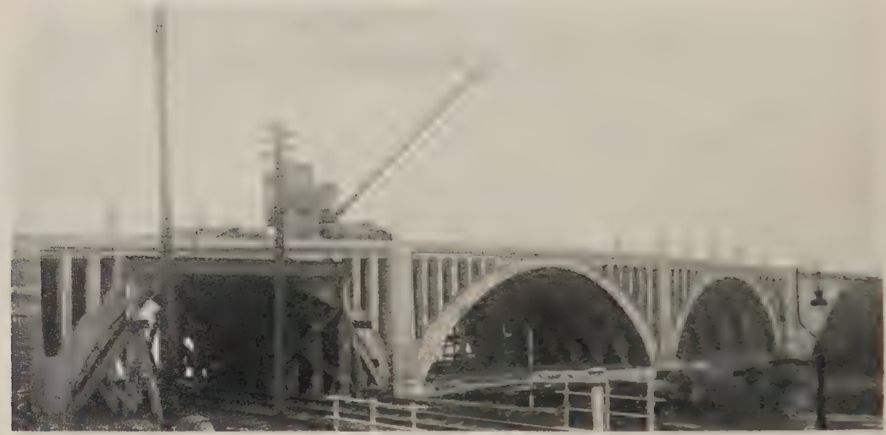


Fig. 290.—Reinforced Concrete Bridge over Southern Railway and River Test.

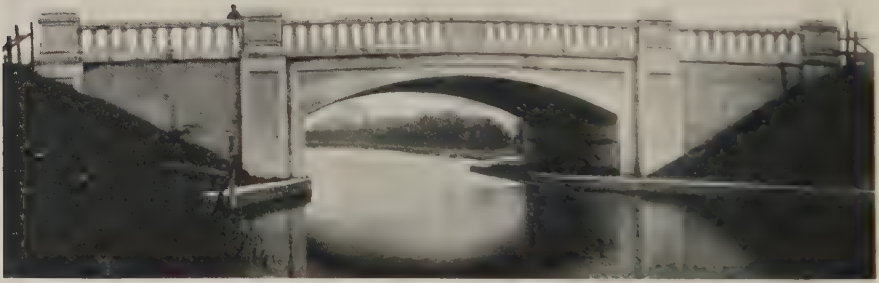


Fig. 291.—Reinforced Concrete Bridge at Garstang.

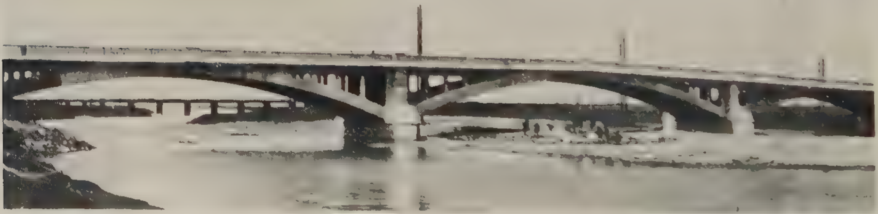


Fig. 292.—Reinforced Concrete Bridge in Cumberland.

loaded, a condition which might cause serious deformation and even failure. The method described so far has the disadvantage that it does not reduce shrinkage cracks and so it is more usual to cast the arch sheet or rib in alternate sections arranged to produce uniform settlement of the centre. Where the extrados is steep a top form must be used to keep the concrete in place.

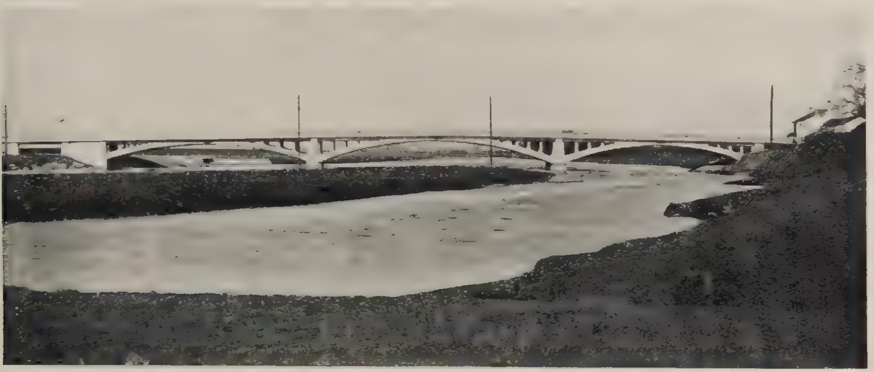


Fig. 293.—Reinforced Concrete Bridge at Longtown.

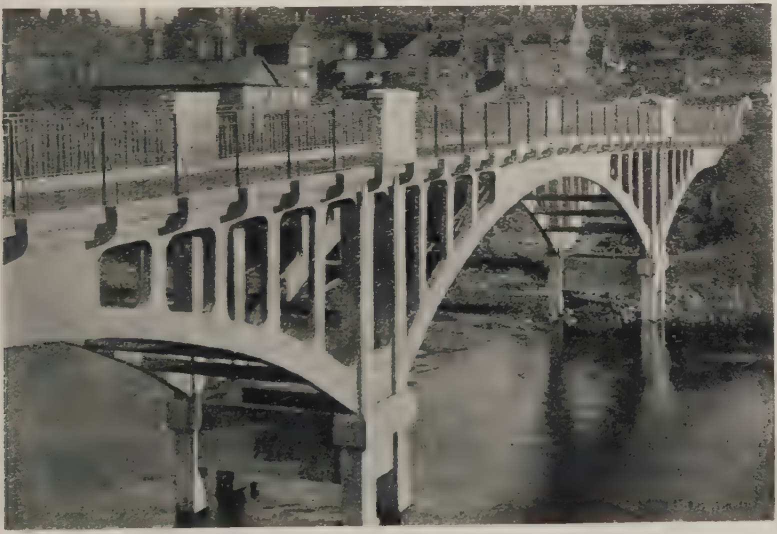


Fig. 294.—Reinforced Concrete Bridge at Ironbridge.

The method adopted for pouring the concrete will depend on the site

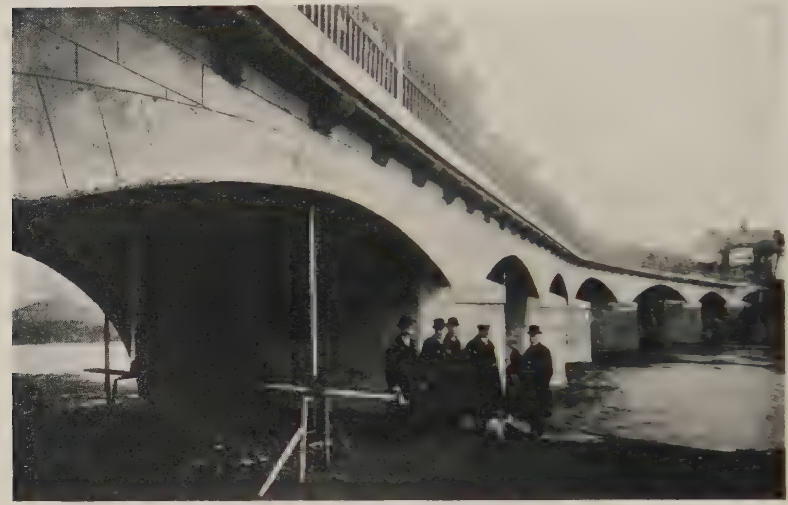


Fig. 295.—Reinforced Concrete Bridge at Tenbury.

Fig. 296.—Reinforced Concrete Bridge at Lymm.

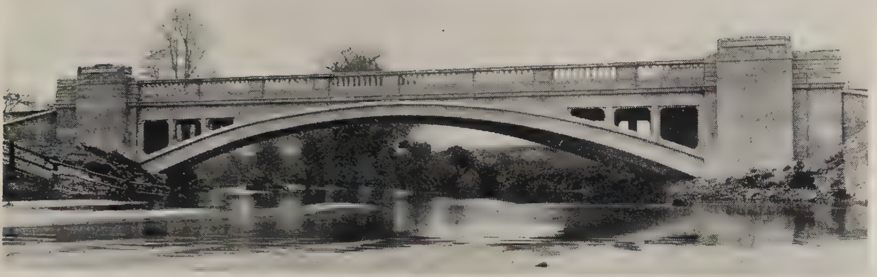


Fig. 297.—Little Hereford Bridge (a Reinforced Concrete Structure).

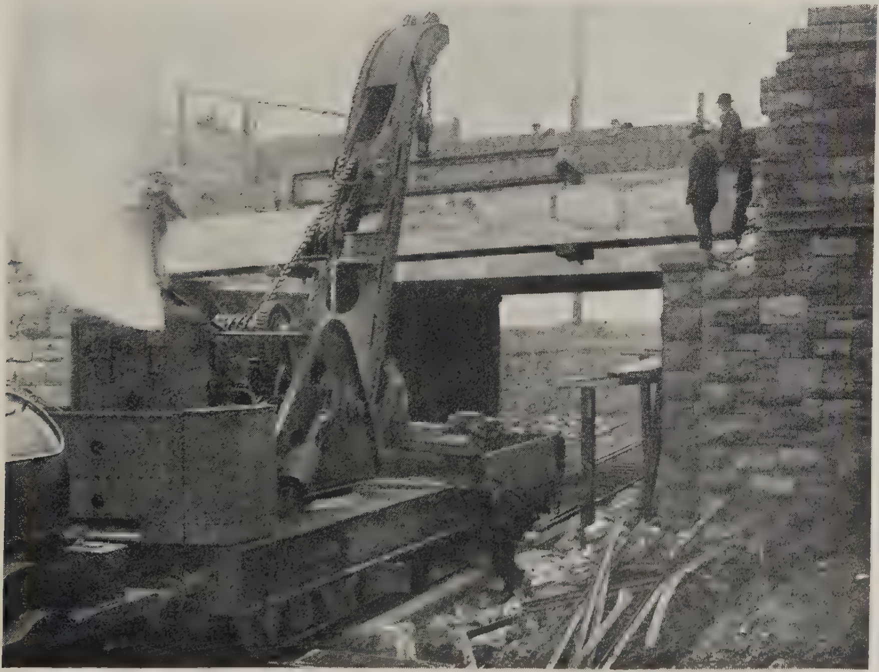


Fig. 298.—Bridge built of Reinforced Pre-cast Sections for the Midland Great Western Railway of Ireland: Sections being lifted into Position.

conditions. Ordinary chuting plant has been employed successfully, but for very long bridges the height of a single tower would be excessive and an overhead cableway spanning the gorge is then preferable.

Reinforcement.—See previous details of steel-fixing in floors. It is common practice to use heavy bars (1½ in. to 2 in. diameter) in bridge beams. These bars should always be bent cold and although it is the practice abroad welding is not desirable unless the working stress on the bars is reduced to allow for the lower efficiency of the weld.

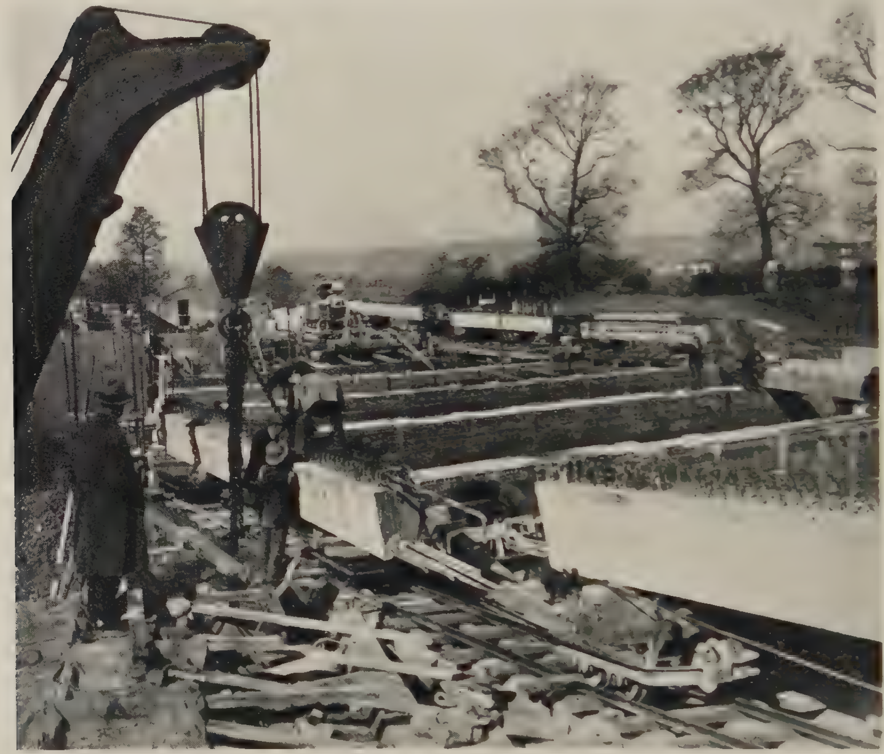


Fig. 299. -Bridge at Mill Hill with Pre-cast Reinforced Concrete Girders.

Culverts

For small discharges pre-cast concrete pipes are the most satisfactory means of draining off flood-water. For a description of these see Part VIII. It is not good practice to use a less diameter than 12 in. however small the discharge, since very small pipes are too readily blocked by obstructions brought down by floods.

The majority of reinforced concrete pipes have ordinary socket and spigot joints, but large pressure pipes are often fitted with reinforced concrete collars covering the plain ends of the tubes (*Fig.* 300). Bitumen is run into the dovetail groove and the joint finished with cement grout. A modern type of patent joint is shown in *Fig.* 301 which is self-explanatory.

Pre-cast pipes are manufactured up to 10 ft. in diameter, but there is not a great demand for such large sizes, most engineers preferring to install a box culvert. The latter is simply a continuous concrete box with reinforced sides, top and bottom (*Fig.* 303). For still larger discharges an arched culvert (*Fig.* 304) with flat or curved invert is necessary. The arch requires comparatively little reinforcement and may be designed as hinged at its springing (*Fig.* 304) or continuous with the footing slab. The latter must be reinforced in the upper face (*Fig.* 305). Considerable care is required in the design of culverts on side-long ground or where it is intended to back-fill on one side only at first. Culverts have been constructed without floors (*Fig.* 306), but this is somewhat risky in certain situations since the footing slabs of the side walls may be undermined. A "cut-off" wall (*Fig.* 307) reaching down at least 2 ft. below the floor level will prevent scour at the ends of the culvert. The wing-walls at the end may be either

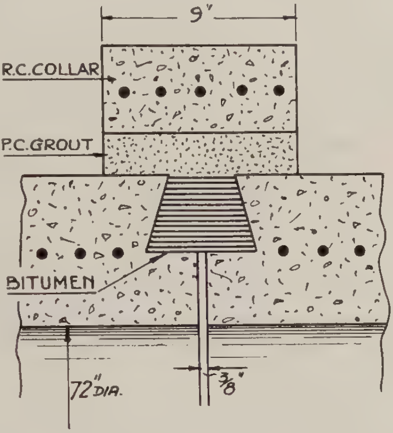


Fig. 300.

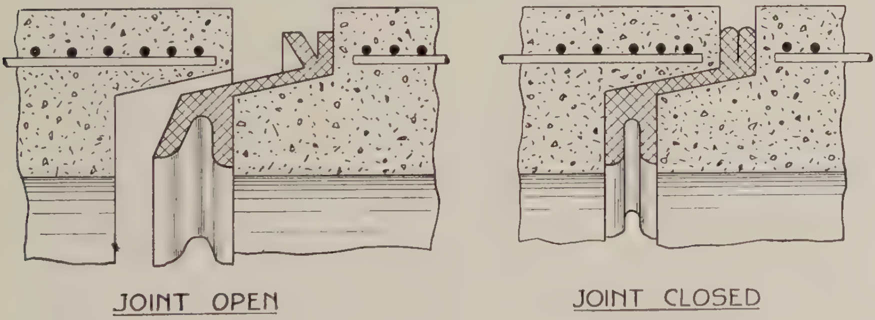


Fig. 301.

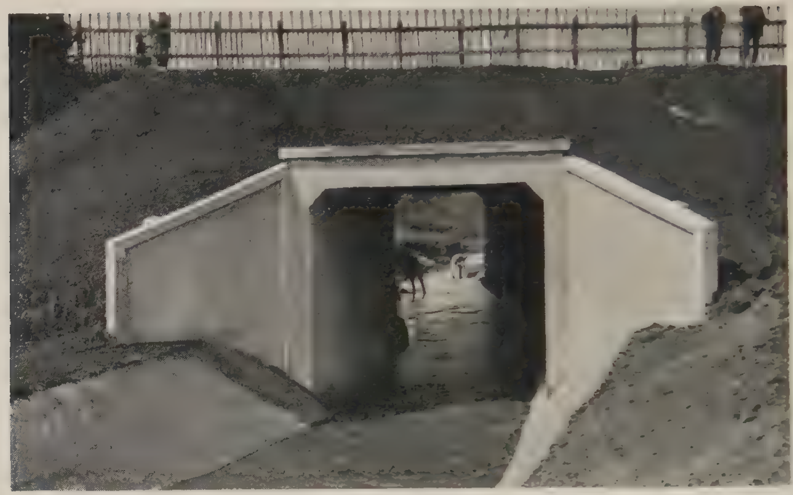


Fig. 302.—Reinforced Concrete Culvert at Bucknall, Staffs.

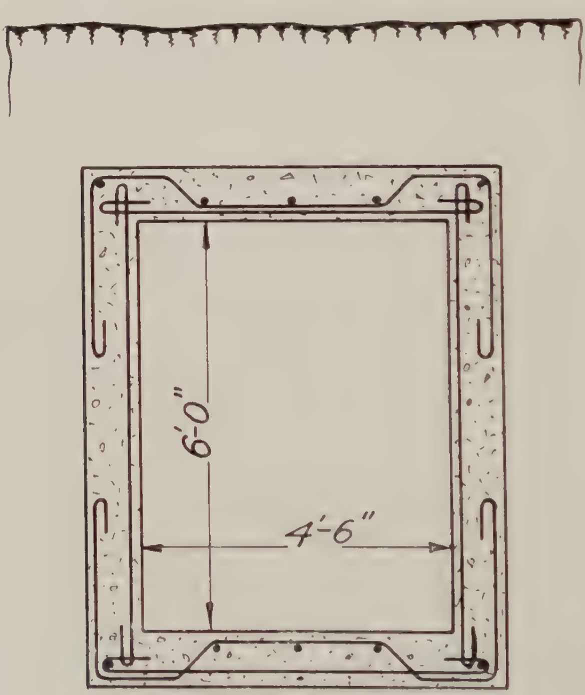


Fig. 303.

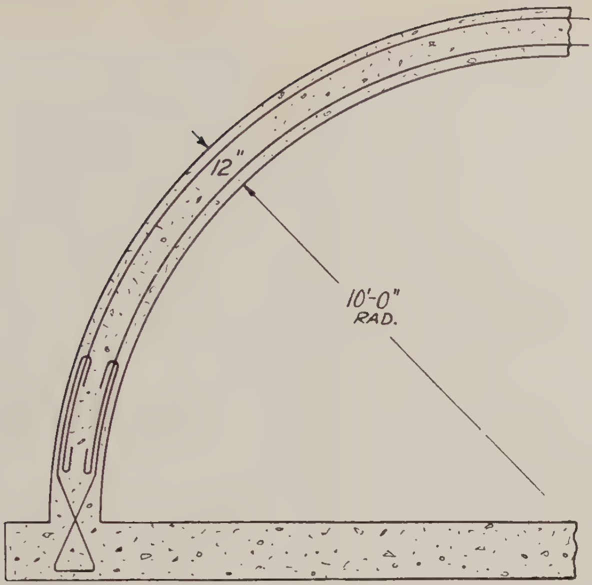


Fig. 304.

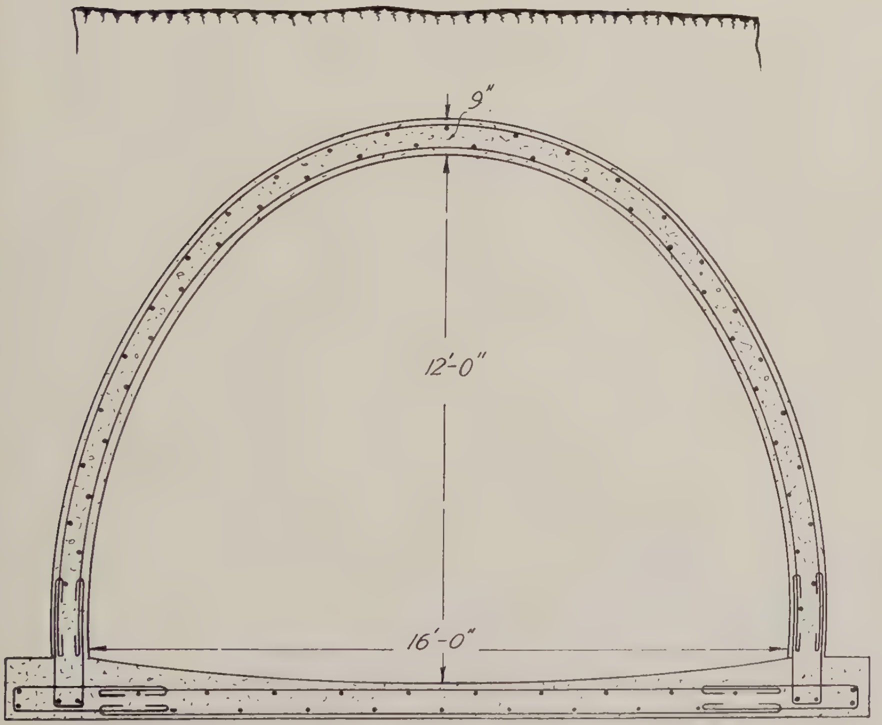


Fig. 305.

in the same line as the sides of the culvert or bent back in plan (*Fig.* 307). A bell-mouth orifice reduces the loss of head due to sudden change of section and therefore increases the amount of water discharged. Wing-walls are designed on the same principle as retaining walls. A dwarf head-wall prevents earth from falling into the stream if a slip occurs.

Unless the road over the culvert is of reinforced concrete a minimum cover of 18 in. of earth is often spread over the concrete slab or arch.

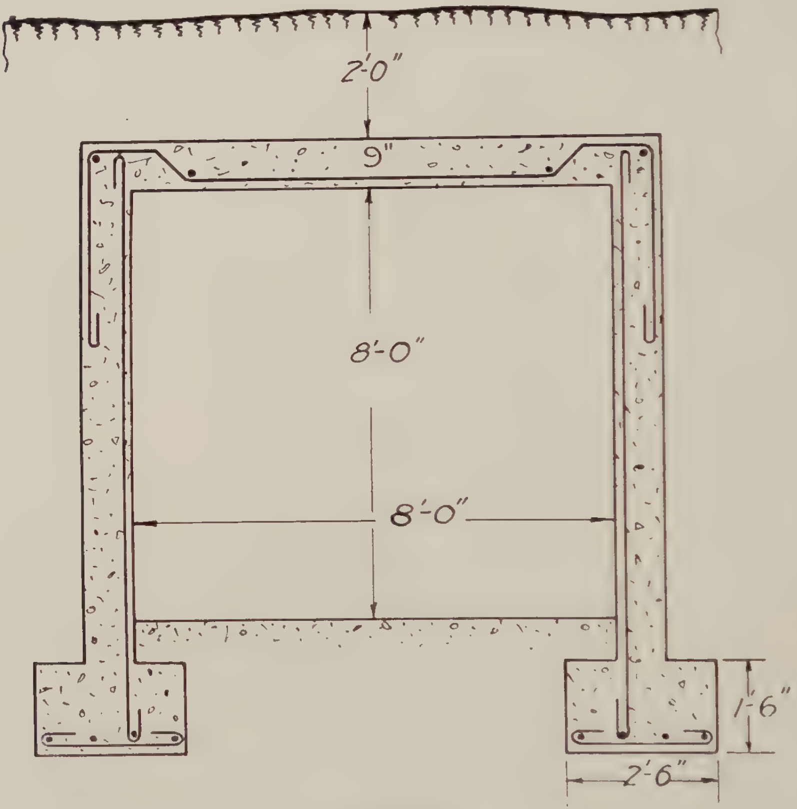


Fig. 306.

Formwork.—Rectangular culverts of plain or reinforced concrete present certain difficulties in the design of suitable formwork. It is not sufficient that the forms shall be easily built and erected; they must also be easily stripped when the concrete has hardened, and it is required to move the forms forward to begin another section of culvert. Except in very short culverts forms are seldom erected for the complete structure before concrete is poured.

A simple method of building a small rectangular culvert is illustrated in *Fig.* 308. As soon as the excavation has been completed the footing slab is poured for its full length. This slab may be of plain concrete mixed in the proportions of 510 lbs. of cement to 11½ cu. ft. of sand and 23 cu. ft. of broken stone where the ground is uniform in nature and of good bearing capacity. On variable or poor ground it is advisable to reinforce the footing slab so as to distribute the load coming on it and prevent any sinking taking place over weak patches. If the slab is reinforced, dowel bars will be left projecting for a length of 40 times their diameter into the side walls, but if the slab is of plain concrete it is generally sufficient to leave a groove on each side, under the middle of the wall, so that the connection between side walls and bottom slab may be improved.

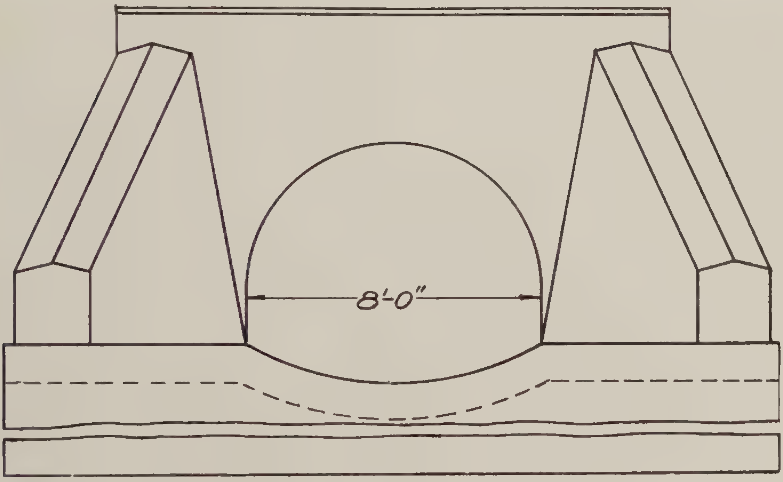


Fig. 307.

Another method often employed is to cast strips of one of the patent joint materials, such as are used in concrete road construction, in the footing slab and allow this to project about 2 or 3 in. above the upper surface of the bottom slab.

While the footing slab is being poured the forms for the side walls will be prepared. The outer wall panels (*Fig.* 308) may be constructed from 7-in. by 1¼-in. or 1-in. boards nailed to 4-in. by 2-in. uprights, the spacing of the latter depending on the thickness of boards used. The ends of the 4-in. by 2-in. uprights rest on the footing slab. The inner wall forms are constructed as panels in a similar manner and should be erected first. Each pair of 4-in. by 2-in. uprights is kept in position by a 6-in. by 1-in. board on edge resting on the bottom slab.

The next step is to erect the roof forms, which consist of 7-in. by 1-in. boards supported by, but not nailed to, 4-in. by 2-in. cross-sills which have been notched at their ends. These cross-sills may be lightly cleated to the uprights if required, and the outer top boards should be bevelled at their outer edges.

The outer wall forms are now erected, the distance-pieces giving the correct spacing between inner and outer panels. The uprights may be supported at the bottom by pegs driven into the ground; $4\frac{1}{2}$-in. by 3-in. walings

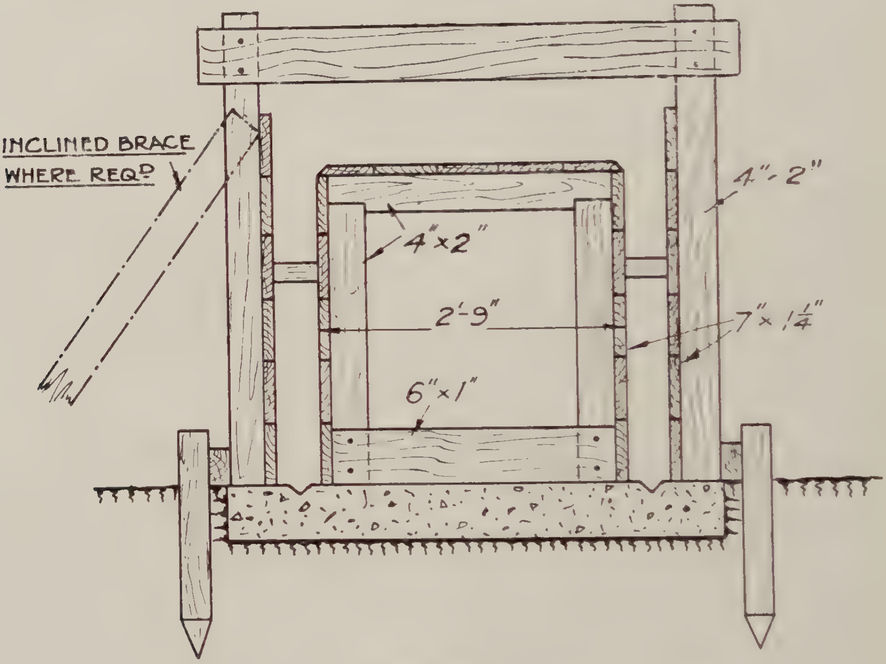


Fig. 308.

or wedges may be used if it is not possible to drive the pegs accurately in position, which sometimes happens in stony ground. The top cross-sill joining the outer 4-in. by 2-in. uprights and any inclined braces required complete the formwork.

This formwork is easily stripped by removing the notched 4-in. by 2-in. sills and letting down the roof boarding quietly when the concrete has hardened.

Normally the concrete would be mixed at the level of the top of the trench and delivered down an inclined chute to a shallow tray placed on top of the roof forms. Another method is to use sufficiently strong sills bolted to the tops of the outer 4-in. by 2-in. uprights and place boards spanning between these sills to form a runway for the barrows used in transporting the concrete.

Formwork for a large box culvert is shown in *Fig.* 309.

Forms for Arch Culverts.—There are several ways of building centres for arch culverts. The governing features will be the foundation conditions, presence of water, span, and rise of the arch. The stream can be diverted around the culvert, or carried in a flume through the culvert, or it may be necessary to confine it within cofferdams to enable the walls to be built in the dry.

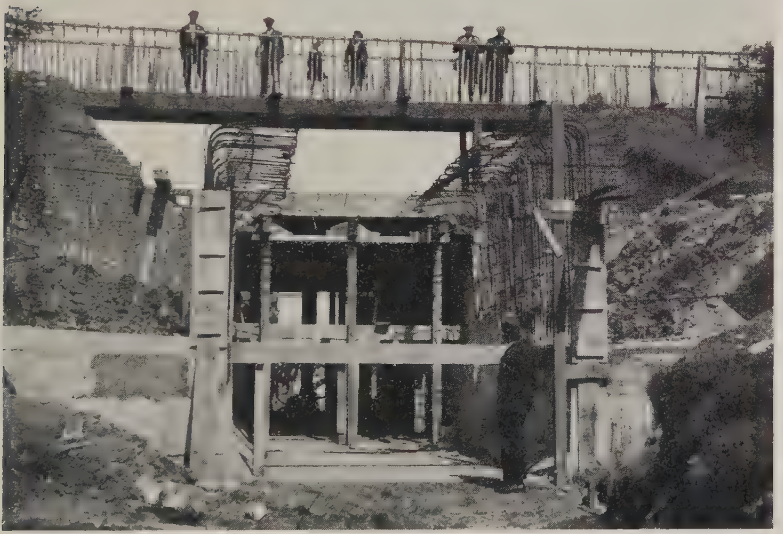


Fig. 309.—Reinforced Concrete Culvert at Bucknall, Staffs.: During Construction.

For small spans, up to say 8 ft. or 10 ft., the ribs need only be supported at the walls, with a tie across at the ends. The centres are set on wedges on top of the wall-form caps. The main requirement of this type of centre is stiffness, so the joints in the ribs, which should be butt joints with cleats, should be securely nailed. The cleats should preferably be also cut to the radius.

For longer spans this type of centre would become distorted, as each joint would tend to act as a hinge, so intermediate shores must be used (*Fig.* 310), either one or two at the crown section and one at each haunch. There are two methods of carrying the shores to the foundation, either by

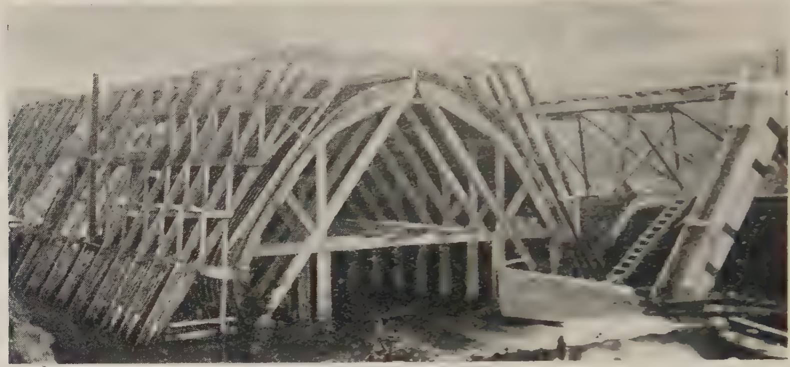


Fig. 310.—Reinforced Concrete Conduit over Ouseburn River.

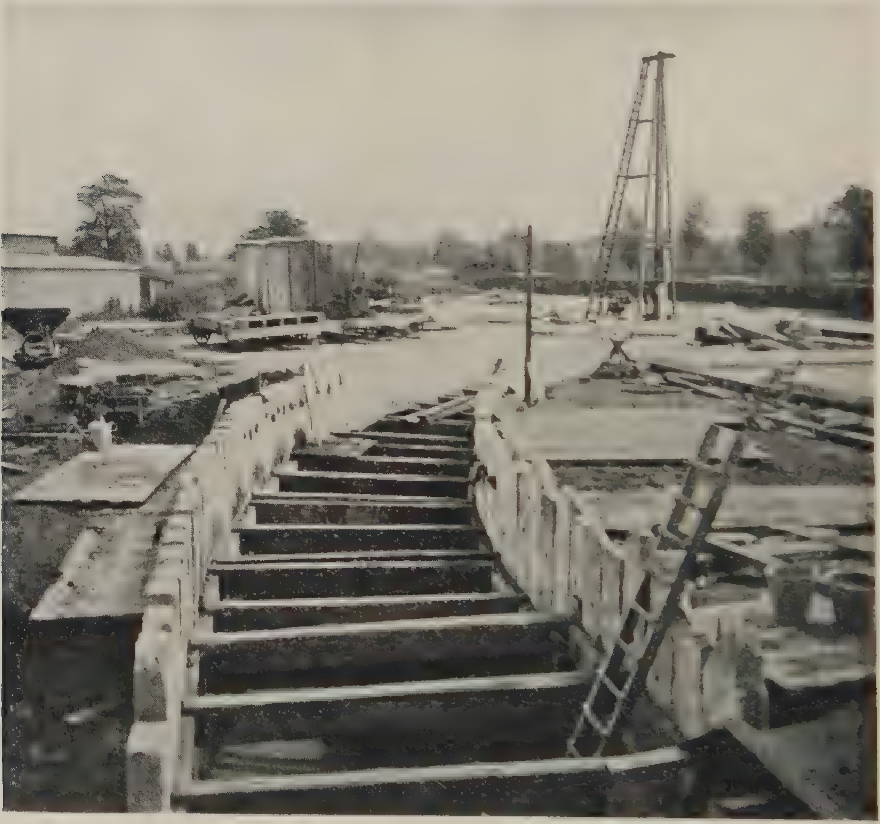


Fig. 311.—Culvert Construction at a Power Station.

concentrating them on a single centre post or taking them directly to a central footing.

Concreting.—In culvert construction the base can be concreted up to the level of the springing points of the side walls, steel dowels being cast in the base to provide a connection between the side walls and the foundation slab. The method adopted for pouring the concrete will depend on the depth of the trench, but the most common practice is to use a metal or timber chute with a wide top which is fed from jubilee skips travelling along the edge of the excavation. The level of the base top is marked by pegs driven into the ground. It is usual to specify that the ends of each day s work shall be kept vertical and not permitted to run to a ragged edge. Some engineers insist on having dowel bars, in a horizontal plane, through the middle of the slab, to connect up one day's work with another. The lengths of these bars should be equal to 80 times their diameter and the amount of projection should be 40 diameters. These bars should not be painted with cement grout. Holes must be left in the stop-board at the end for the dowels to run through.

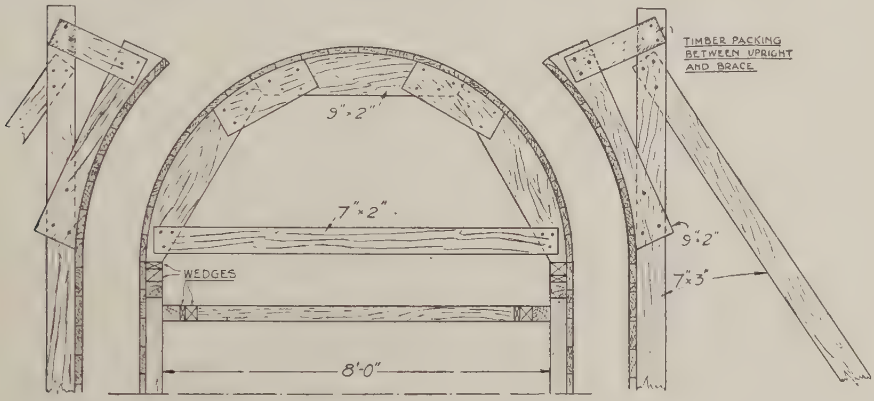


Fig. 312.

To prevent the formation of large cracks in the culverts the concreting is often done on the alternate-bay system.

Where the outer surface of the culvert walls is steeply inclined to the horizontal it is necessary to use a top shutter (*Fig.* 312) to keep the concrete in place. This shutter is built up as the operation of concreting progresses and must be wired down to the reinforcement or otherwise held in position so as to resist the upward pressure due to the wet concrete.

Arches up to 6-ft. or 8-ft. span may be stripped in 5 to 10 days ; from 8-ft. to 15-ft. span in 10 to 15 days. The time must be judged from existing climatic conditions.

Aqueducts and Flumes

Reinforced concrete has been extensively employed in the construction of aqueducts both in Great Britain and abroad and for irrigation flumes in the Dominions. The design of such structures is a comparatively simple matter except in cases where high trestles are required to support them. In the latter case the side walls are usually constructed with top and bottom ribs (*Fig.* 313) connected by a thin side wall which acts as the web of the girders thus formed and the trestle legs are rigidly braced. The floor is hung from the side wall girders which are supported on a capping piece running transversely to the aqueduct and carried by the trestles. High trestles require special provision against uplift due to wind blowing on the side of the superstructure.

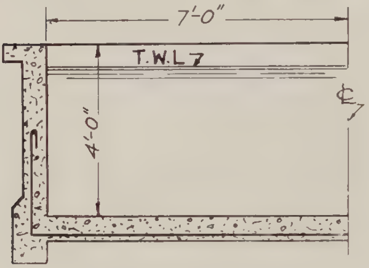


Fig. 313.

Open channels in excavated ground and following the hydraulic gradient,

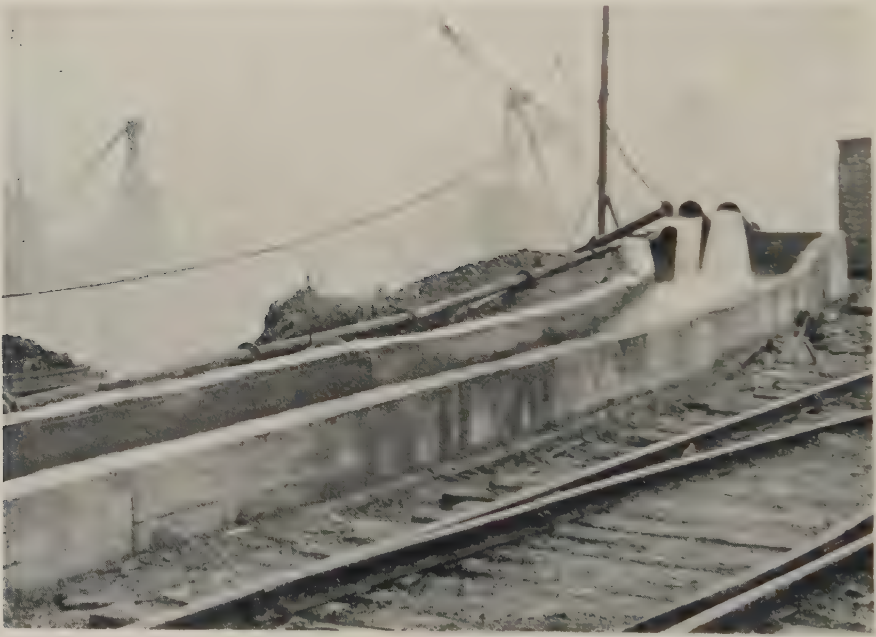


Fig. 314.—Concrete Flume at Tilbury Docks Extensions.

not being under pressure, only require sufficiently thick walling to prevent leakage of water and to resist earth pressure before the channel is filled. The conduit constructed for the British Aluminium Company at Kinlochleven is rectangular in shape, 8 ft. by 8 ft. inside, with reinforced concrete walls 9 in. thick at the bottom and 6 in. at the top. The roof is a 4-in. reinforced slab and the invert has a 3-in. granolithic finish. The total length of this conduit is 3½ miles.

The concrete flume shown in *Fig.* 314 is interesting as being a "temporary work" in connection with the Tilbury Dock extension.

Overflows and Weirs

In many hydraulic structures such as irrigation channels, dams, headraces, etc., overflows are very essential. If the crest is constructed in reinforced concrete it may be cantilevered off the side wall if necessary. The syphonic overflow (*Fig.* 315) is peculiarly useful owing to its high efficiency and the fact that it commences to operate at its maximum discharge under a very small flood, unlike the ordinary rectangular weir which has a very small discharge when the head is small. It is usually constructed of concrete and where the outlet is small and the inner forms are not easily stripped a casting is left in the concrete to give the required shape to the outlet. By making the discharge pipe of the syphon of suitable cross-section the syphonic overflow may be constructed to work on a head greater than 34 ft. which is the ordinary limit for syphons constructed at mean sea-level.

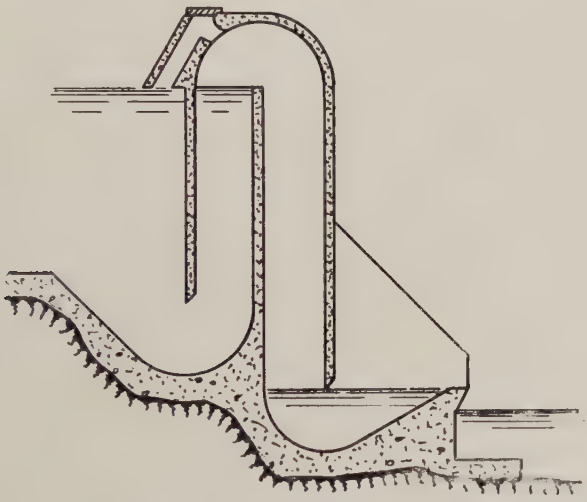


Fig. 315.

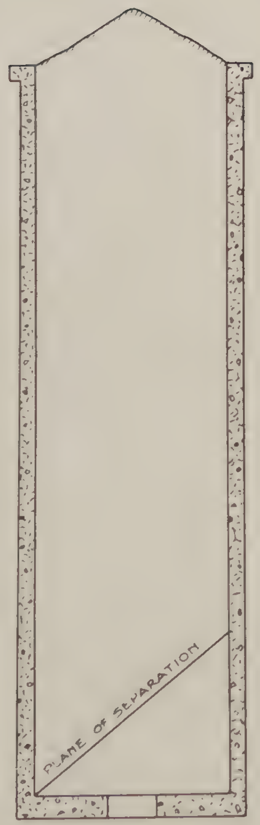

PLANE OF SEPARATION

Fig. 316.

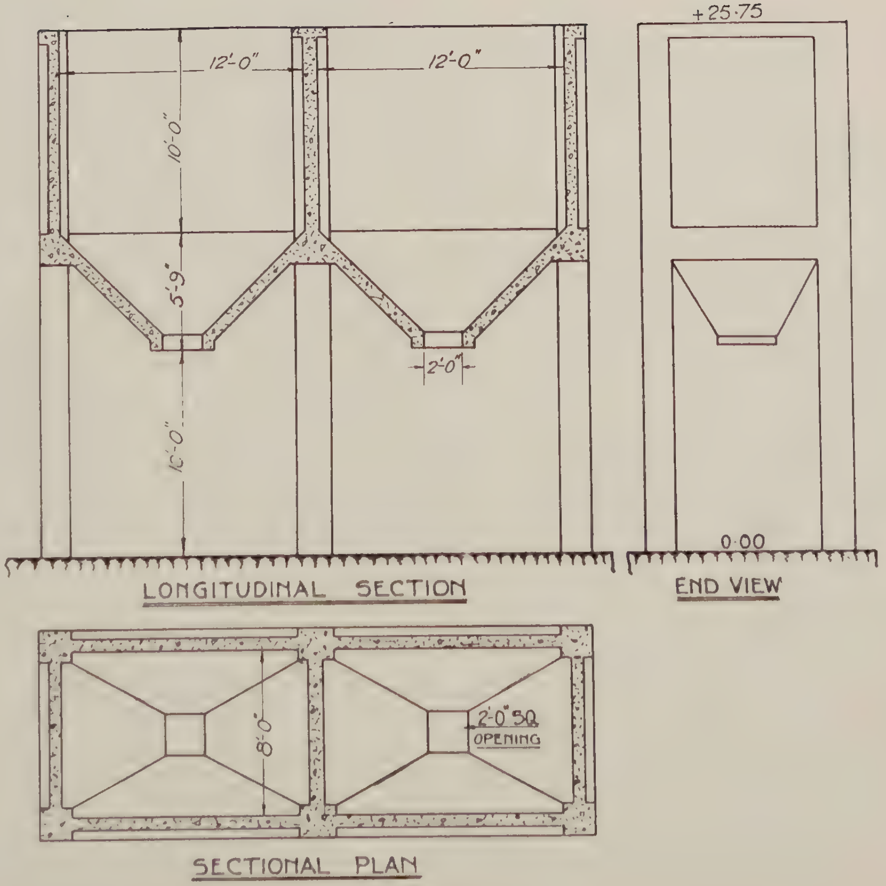
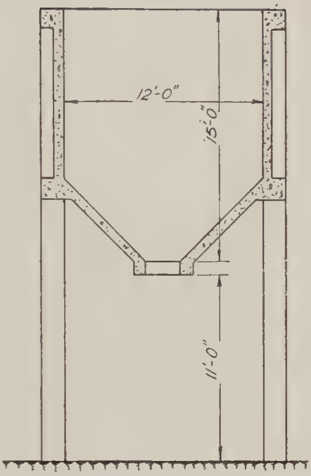

12'-0"
12'-0"
10'-0"
5'-9"
10'-0"
2'-0"
LONGITUDINAL SECTION
+25·75
0·00
END VIEW
8'-0"
2'-0" SQ.
OPENING
SECTIONAL PLAN

Fig. 317.

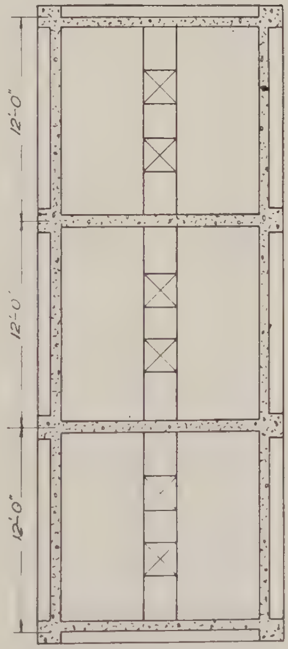
Bunkers, Hoppers and Silos

Under one of the above names are included all types of the overhead containers for coal, coke, ashes, stone, etc., which are a feature of most industrial works. It would be better however if the title silo were reserved for "deep" bunkers, i.e. those in which the plane of separation of the material cuts the opposite side of the bunker before emerging from the filling (*Fig.* 316). In shallow bunkers this plane cuts the surface of the filling before meeting the opposite side of the bunker, and the pressure on the sides of the bunker is calculated in the same way as is used in retaining wall design. In "deep" bunkers a very large proportion of the filling is held up by friction on the side walls and the actual pressure intensity on the bottom of the bin is small. The lateral pressures due to filling coal in bunkers or behind walls are great, although they do not reach the magnitude of water pressure. There have been several cases of failure where grain or coal has been piled up against a thin brick wall to an excessive height. The calculation of the stresses in bunkers of any kind is one to be investigated by a specialist and cannot be explained here. It is sufficient to state that all vertical walls must be designed for lateral pressure and partition walls must be reinforced on both sides since one compartment may be full while the other is empty.

Bottom.—Bunker bottoms are made (1) with one sloping and three vertical sides of which two have a triangular elevation; (2) pyramidical, i.e. sloping in four directions (*Fig.* 317); and (3) trough-shaped or sloping in two directions (*Fig.* 318). The last type of bottom may be designed with two sloping and one horizontal slab if the opening is required in a horizontal plane. If the bunker is circular in section in its upper portion the bottom is usually conical.



CROSS SECTION



SECTIONAL PLAN

Fig. 318.

Hemispherical bottoms are to be avoided owing to the excessive cost of formwork required. The bottom is hung from the side walls by steel in tension carrying the filling and the dead load due to the reinforced concrete slab, lining and gate mechanism.

Column Spacing.—The width between columns should not be less than 12 ft. if the coal is to be removed in wagons or lorries, but if a conveyor belt is to be used this width may be diminished. The headroom under the opening will also depend on the method of removal of the coal. The columns must be designed to carry the whole dead weight coming on them, including the weight of the conveyor house or screens if these are supported above the bunker. They must also be strong enough to resist the wind pressure acting on the whole of the exposed surface.

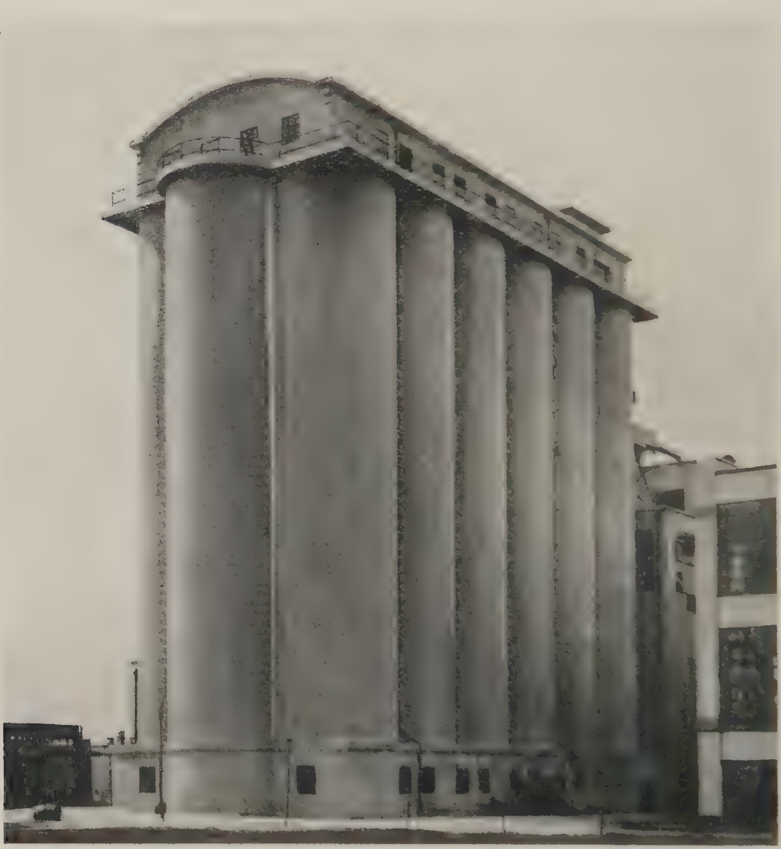


Fig. 319.—Reinforced Concrete Grain Silos at Welwyn (Capacity 200,000 Bushels).

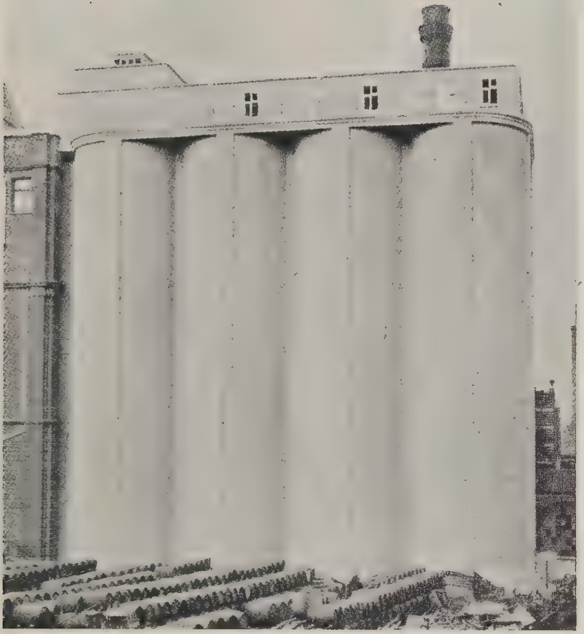


Fig. 320.—Reinforced Concrete Silos at Silvertown.

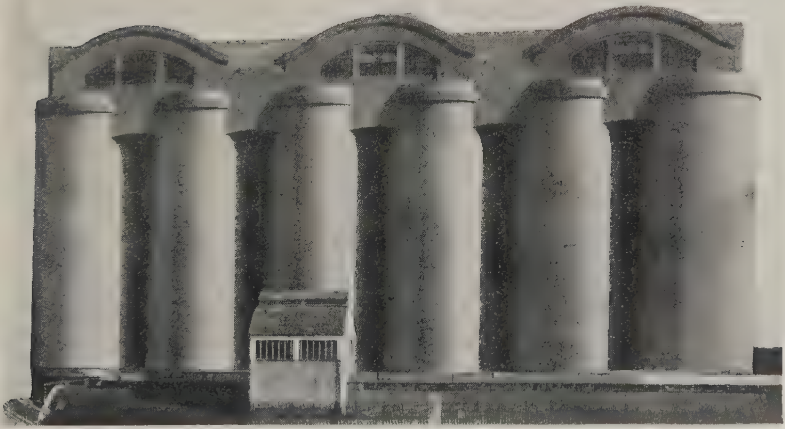


Fig. 321.—Reinforced Concrete Silos at Erith.

Long series of bunkers should be divided up by expansion joints which may be covered with a loose tee-iron where the break occurs in the bottom slab. At expansion joints the columns are generally duplicated. The expansion joints of bunkers to hold wet coal should be filled with bitumen.

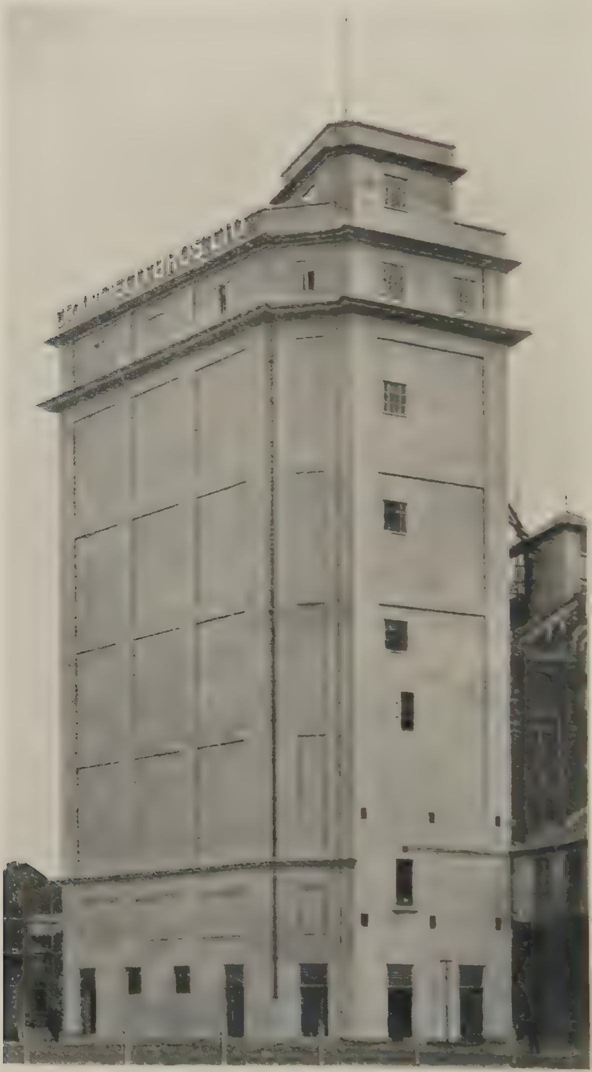


Fig. 322.—Reinforced Concrete Grain Silos, Ipswich.

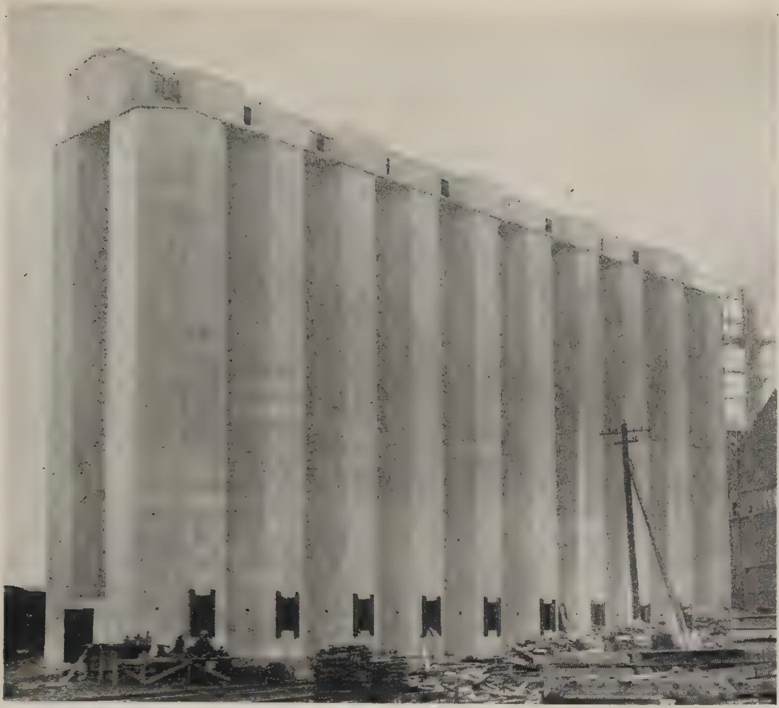


Fig. 323.—Reinforced Concrete Silos for Storing Cement.

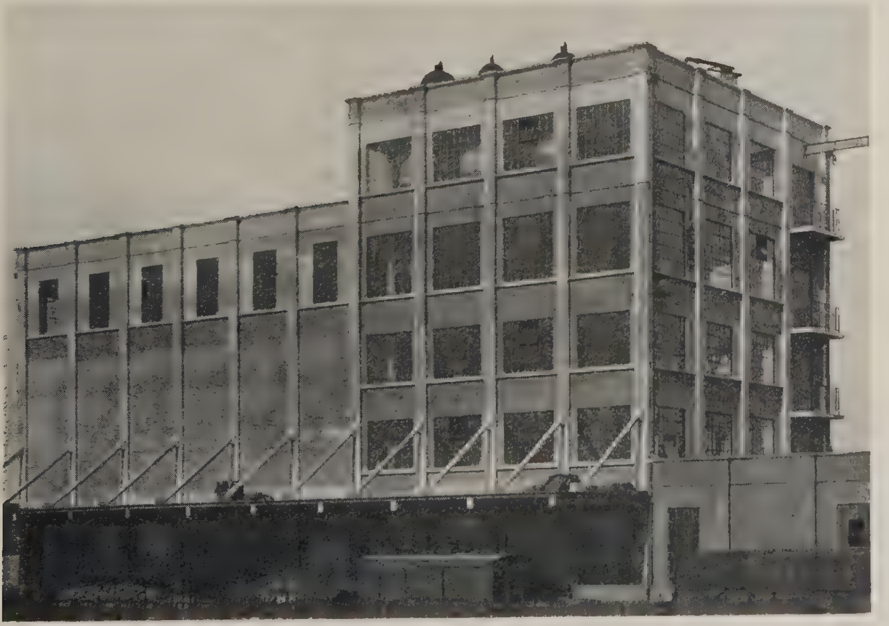


Fig. 324.—Reinforced Concrete Cereal Store and Provender Mill, Nocton.

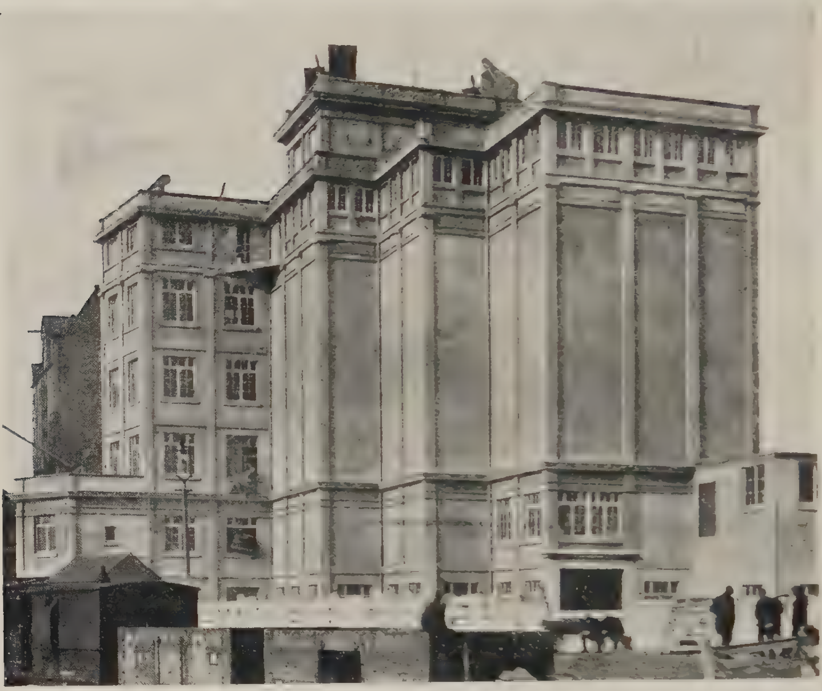


Fig. 325.—Reinforced Concrete Grain Silos and Mills at Edinburgh.

The column footings may be isolated or the columns may be supported on the rib of a circular inverted tee-beam continuous from column to column and with a flange sufficiently wide to reduce the ground pressure to the limit desired.

Lining.—The methods adopted for filling bunkers include (*a*) elevators taking the material from a boot or pit below ground level and filled from railway trucks, (*b*) overhead conveyor belts, and (*c*) overhead gantries carrying trains of coal wagons. In the last case the railbearers span between the partition walls of the bins which must be stiffened up with pilasters under the railbearers (*Fig.* 326) if the walls are, as usually, of light cross-section. A lining of blue Staffs. tiles is often laid over the concrete bottom where the bunker is to contain material of a particularly abrasive nature such as coke. The size of opening varies with the size of filling to be

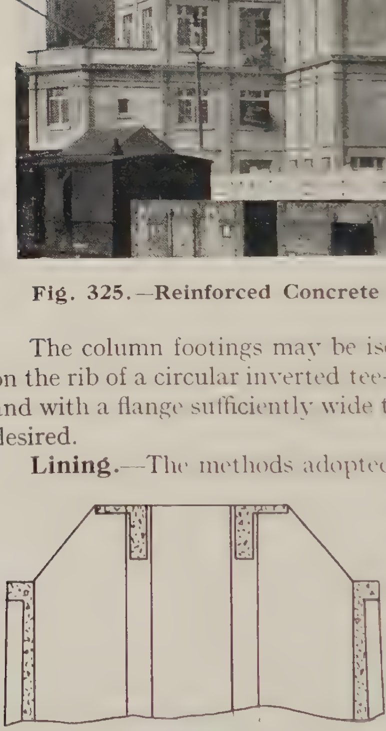


Fig. 326.

stored; for pieces up to 6 in. in size an opening of not less than 2 ft. square is desirable. Where material which is likely to clog is stored probing holes must be inserted in the sloping slabs. For fine filling these should be provided with a metal cover. Batteries of circular bins are often constructed so that the spaces between them may be used for storage purposes. Smaller sizes of circular bunkers have been constructed of pre-cast blocks or of pre-cast staves held together by tension steel passing round the circumference of the bins.

Construction.—Formwork is described under the sections dealing with footings, columns and walls. The special forms required for bunker bottoms may be strutted off the column braces and are somewhat similar in design to the top forms for pyramidical footings. If the boards run lengthways down the slope the braces may be either all timber or $\frac{5}{8}$-in. bolts on two sides. Top forms are nearly always required for the bottom slab since its slope is made not less than 35 degrees with the horizontal.

Concreting.—Undoubtedly a hoist or mast is the best plant for use in concreting bunkers which are square or nearly so in plan. If the number of cu. yds. of concrete to be poured is small, as in certain types of ash-hoppers, a simple cat-head supported from the scaffolding is often used, as the plant charges due to the employment of a more efficient type of pouring plant would be excessive when distributed over the small yardage to be poured. A fairly wet concrete is required in order to ensure that the steel shall be well bonded to the concrete and that the wall shall be free from honeycombing.

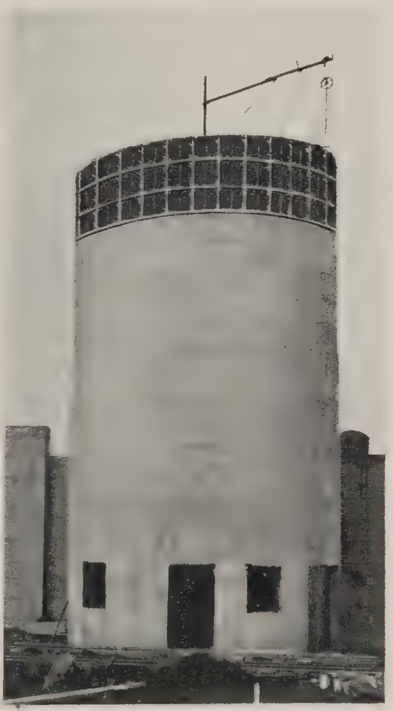


Fig. 327.—Metal Forms in Silo Construction.

Reinforcement.—Although in small bunkers for storage of light materials only very light reinforcement is required it is not desirable to use bars of less than $\frac{1}{2}$-in. diameter in the walls and bottom slab. Smaller bars are extremely difficult to keep in place while the concrete is being poured and, particularly in the upper parts of slabs, should be avoided. So far as possible the reinforcement should be built and wired up on

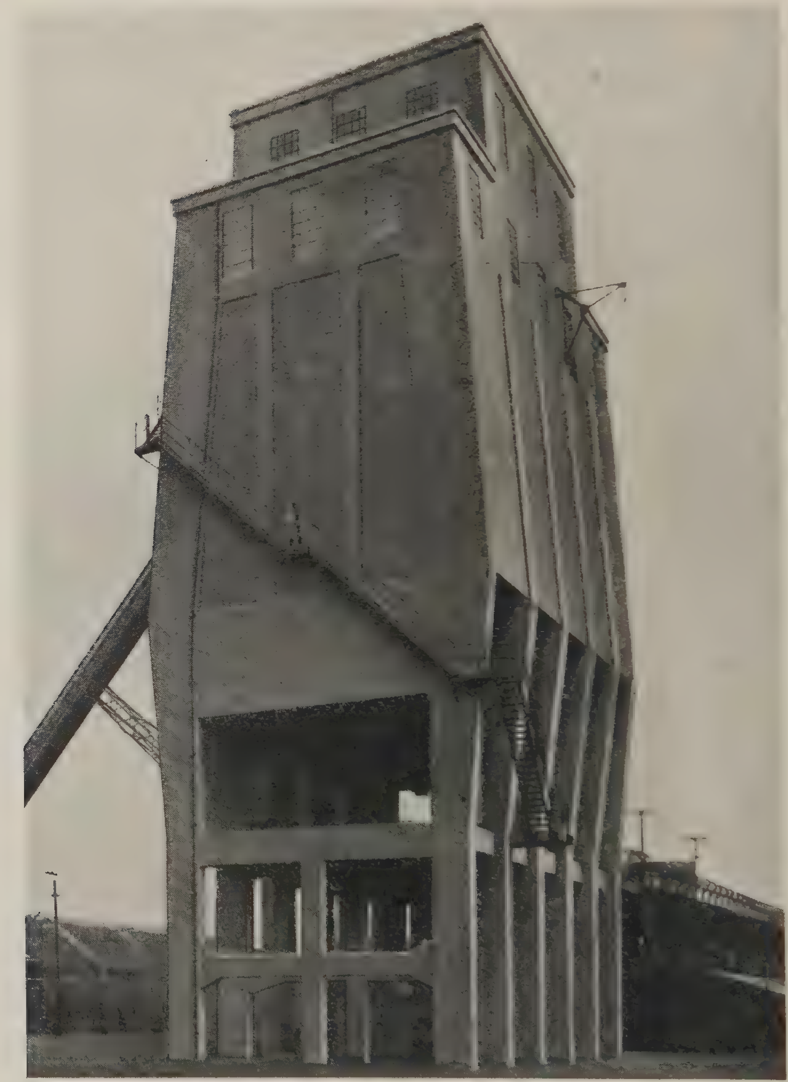


Fig. 328.—1,000 Tons Reinforced Concrete Storage Bunkers at Dowlais.

the bench and hoisted as units. In circular silos the circumferential bars should lap at least 40 diameters and should be bent in a hooping machine.

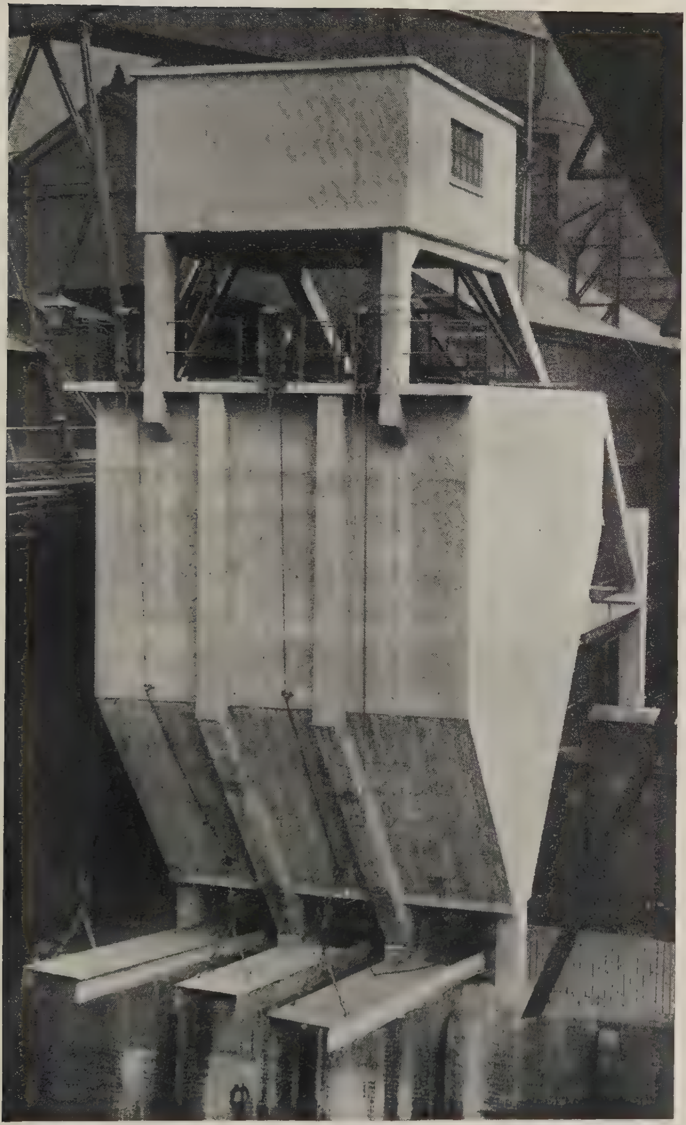


Fig. 329.—Reinforced Concrete Ash Bunker at Greenwich Power Station.

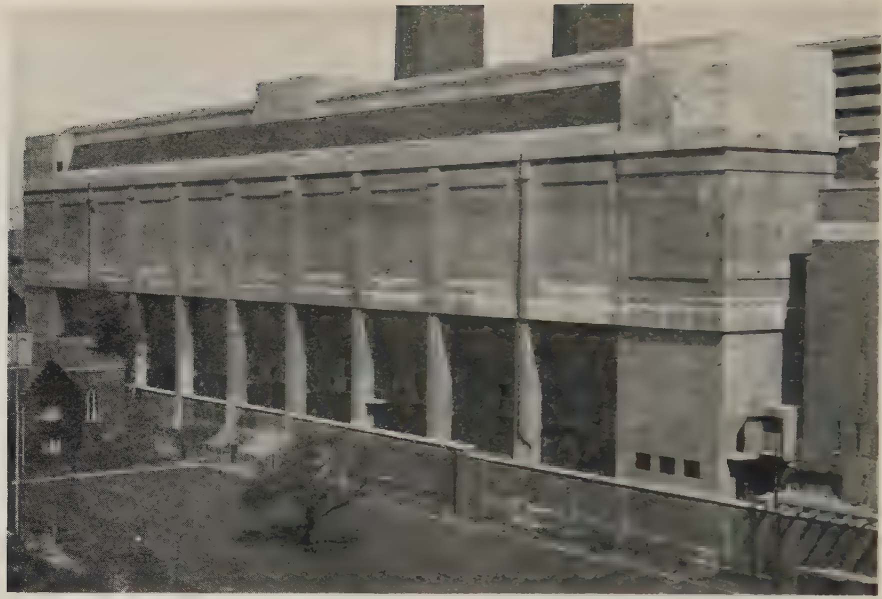


Fig. 330.—10,000-Ton Reinforced Concrete Coal Bunker at Greenwich.

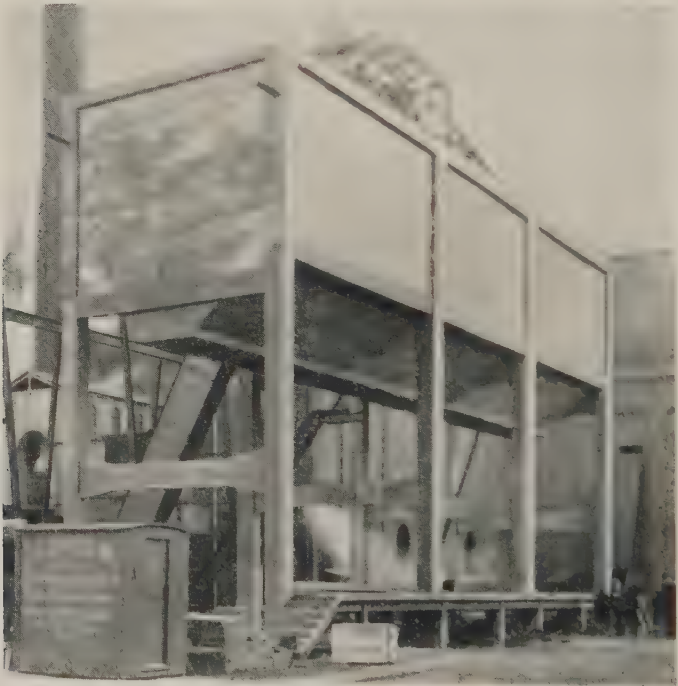


Fig. 331.—Reinforced Concrete Coke Bunkers at Hull (capacity 200 Tons).

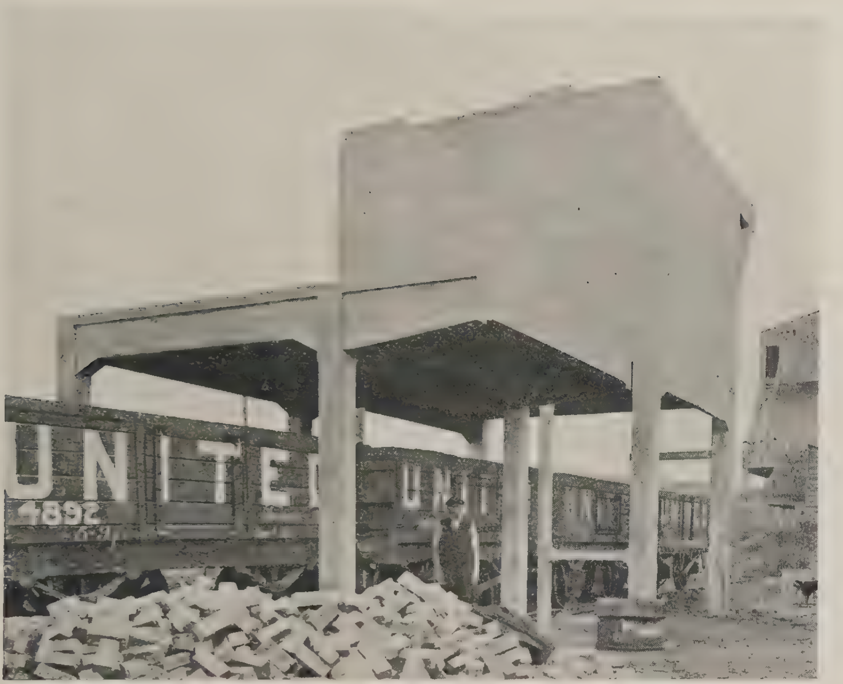


Fig. 332.—Reinforced Concrete Storage Bunker at Airdrie.

Water Towers

Extensive use has been made of reinforced concrete in the construction of elevated water tanks—either circular or rectangular in plan to act as service supplies to works and towns. For the circular form (*Fig.* 333) the design is similar to that of cylinders under internal pressure, the reinforcement being ample to resist all the tensile stresses caused by the pressure. It is usual to work to a low stress in the steel, say 10,000 lbs. per sq. in. It is necessary to take care that the tensile steel hoops are adequately lapped. It is only in the smallest tanks that the bars may be used in single lengths to encircle the periphery of the walls. The laps in successive rows of bars should also be staggered. In addition to the hoop steel it is usual to insert vertical bars to act as distributors and provide fixation at the junction of the wall and floor.

The supports to the floor slab may be arranged as a series of radial beams, but this often causes "crowding" of the steel at the centre if the beams are continuous there. In small tanks the floor may be supported on four beams connecting the tops of the four columns and arranged so as to form a square in plan. In such floors the reinforcement of the slab will be arranged in mesh form, that is, with two rows of bars in rectangular directions.

Rectangular tanks on several rows of columns (Fig. 333) may be designed

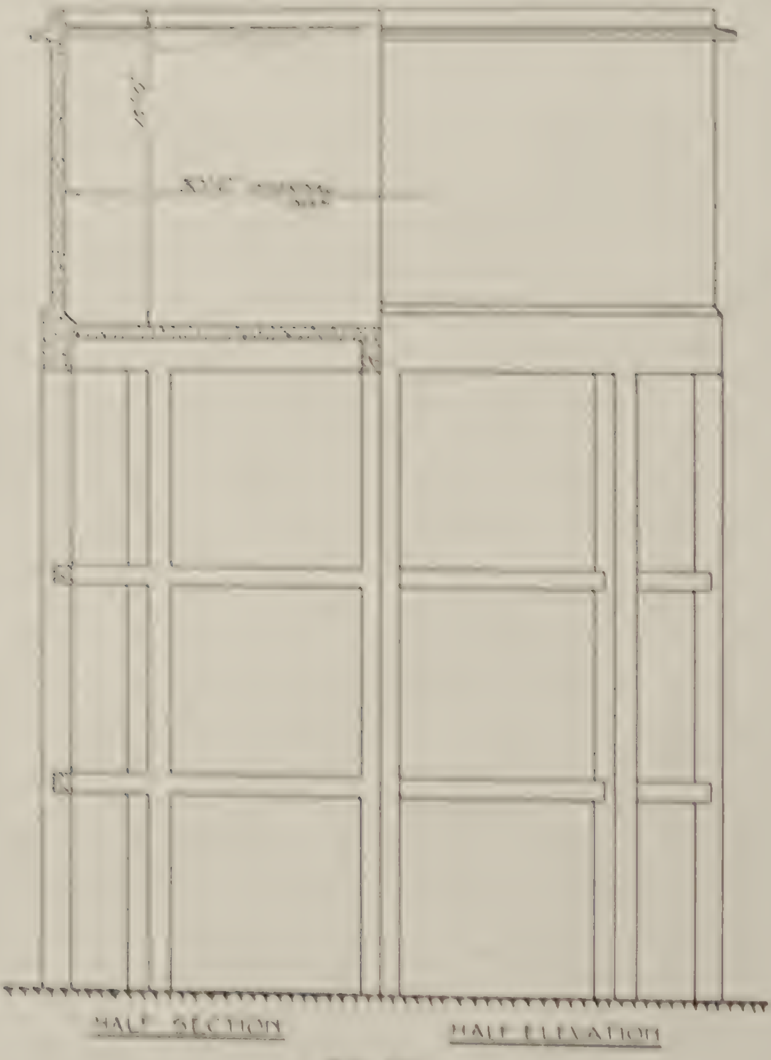


Fig. 333.

so that the side walls act as cantilevers in resisting the water pressure and as girders in conveying the load from the floor slab to the columns. The

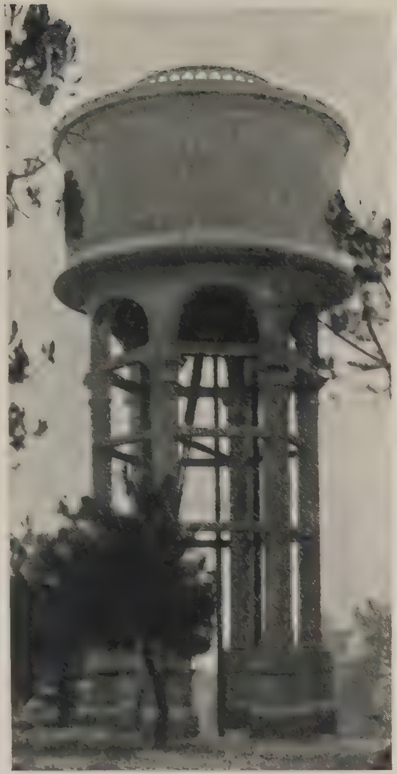
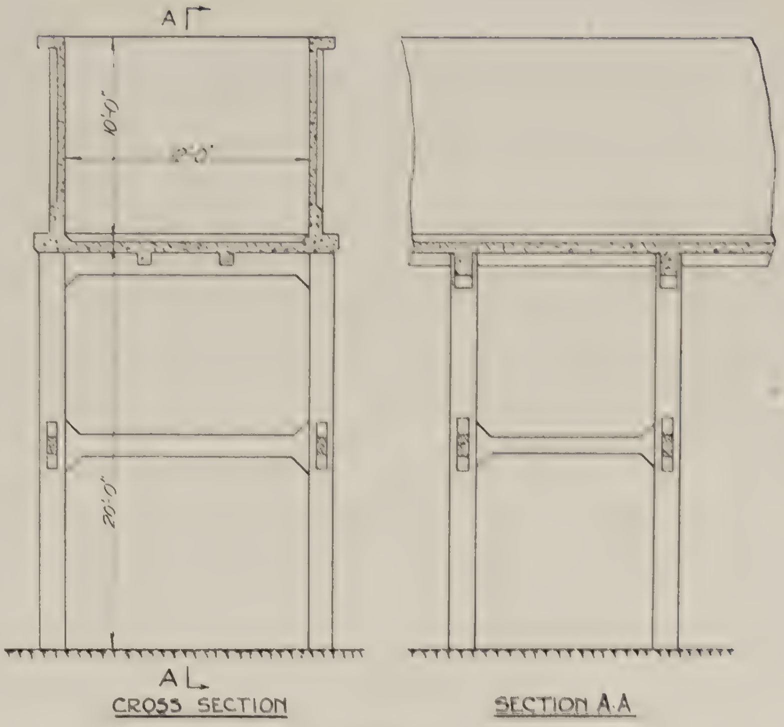


Fig. 334.—Reinforced Concrete Water Tower at Bournemouth.



A
10'0"
20'0"
A
CROSS SECTION
SECTION A.A

Fig. 335.

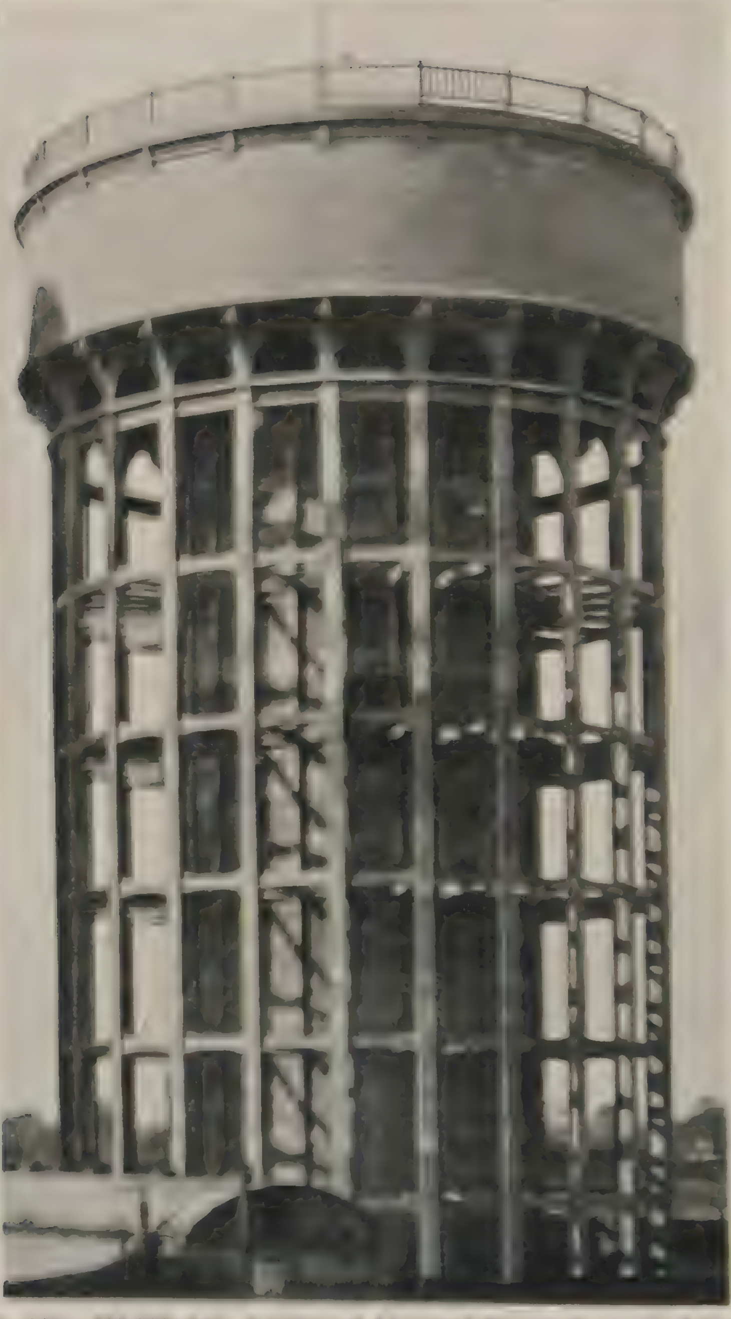


Fig. [illegible].—150,000 gall. Reinforced Concrete Water Tower at Leeds.

direct load on the latter must be combined with the bending moment due to the wind pressure on tank and columns in order to calculate the stresses in the columns. In estimating the load on the columns and footings it must not be forgotten that the wind causes an extra thrust over and above that due to the dead loads from the tanks and water.

Separate footings for the columns are not usually considered desirable since the settlement of the columns when the tank is filled may not be uniform. A foundation on a raft or on a circular inverted tee-footing is often preferred. Care must be taken to investigate the stability of the tower when the wind blows on the empty tank and, if necessary, the columns must be anchored securely in the ground.

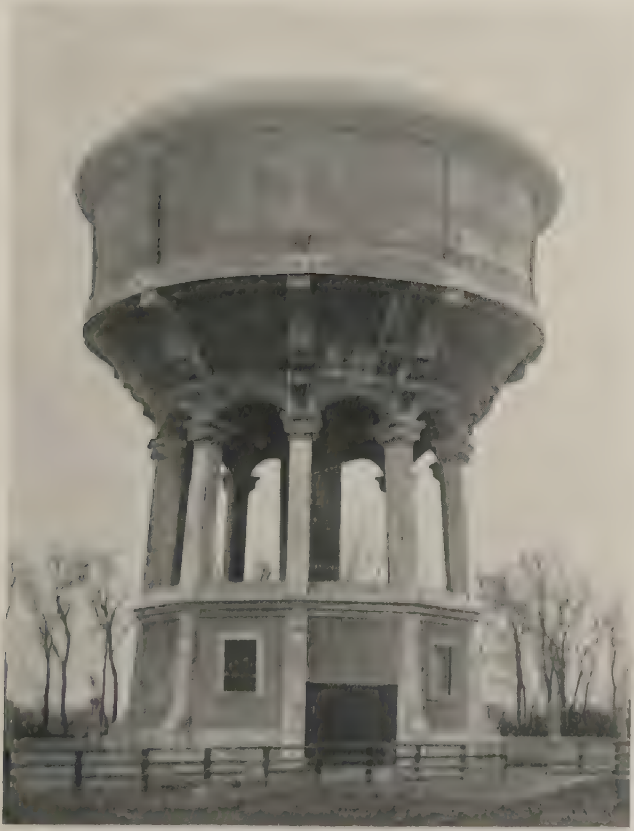


Fig. 347. Reinforced Concrete Water Tower at Hornsey.

Provision must be made for a ladder and, in roofed-in tanks, for a manhole and cover. A lightning conductor is also desirable. In addition to the inlet and outlet pipes, overflow and scour pipes are also necessary.

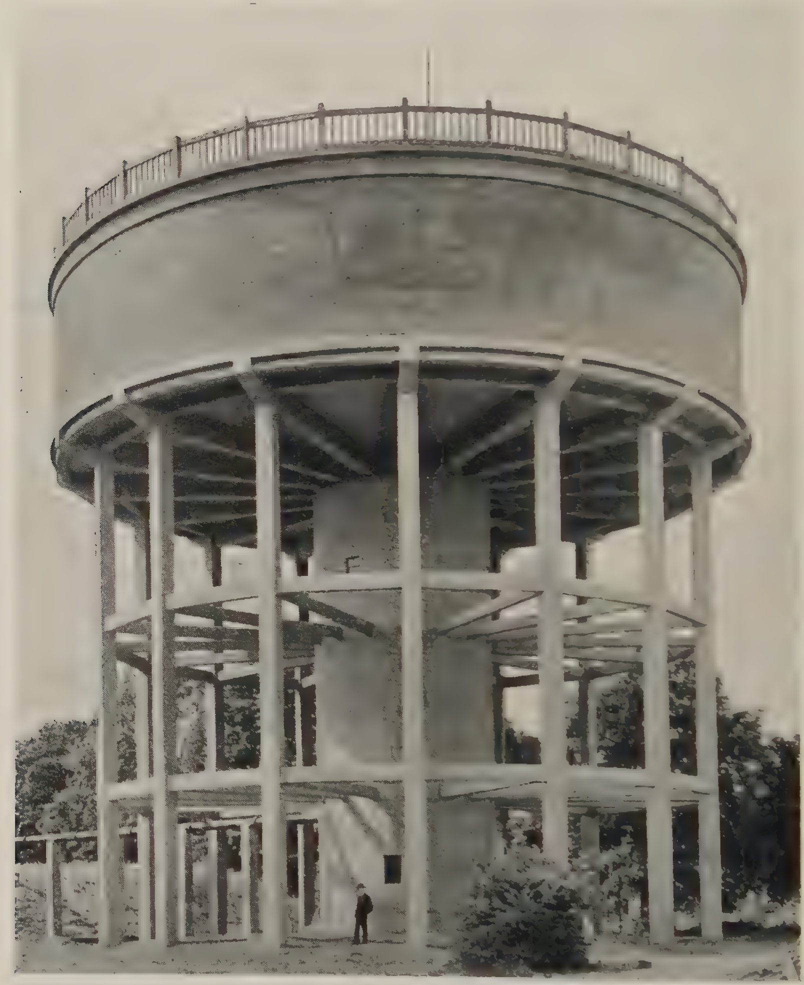


Fig. 338.—410,000-gall. Reinforced Concrete Water Tower at Brentwood.

The formwork for columns and walls has already been described in this Part.

The process of concreting high tanks is best carried out by means of a mast or hoist. Waterproofing the concrete is unnecessary if a mix not leaner than 1 : 1½ : 3 be used and the grading and placing are efficient, but it is sometimes specified that Hydralime be used in the proportion of 10 per cent. of the weight of the cement. In cases where leakage occurs a 2 to 1 rendering with the addition of 10 per cent. of Hydralime should produce a watertight structure.

Figs. 334 and 336 to 343 show elevated water towers of varying heights and of capacities ranging from 1,000 gallons to 750,000 gallons.

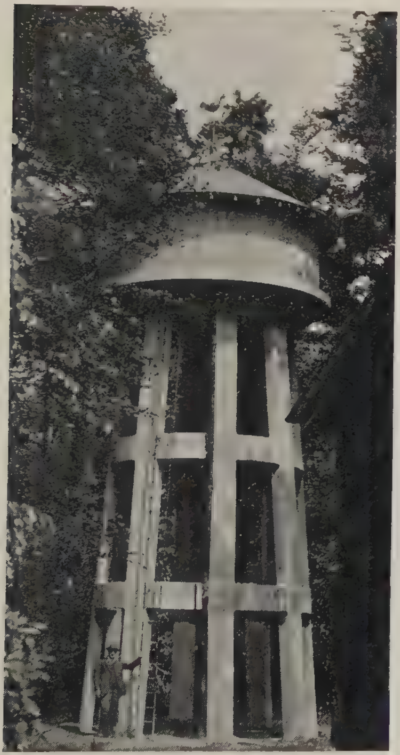


Fig. 339.—1,000-gall. Reinforced Concrete Water Tower at Bransgore, Hants.

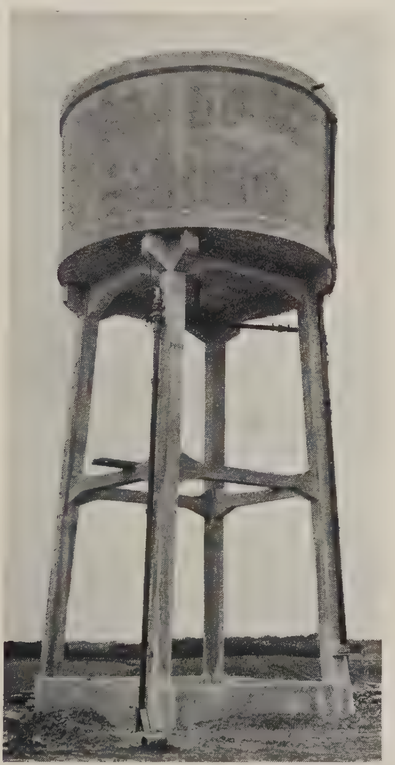


Fig. 340.—20,000-gall. Reinforced Concrete Water Tower at Bishopbriggs.

Cooling Towers

Timber alternately wet and dry decays very rapidly so that wooden cooling towers have a life of only from 12 to 15 years. Protection of the timber by impregnation with tar products renders the towers liable to destruction by fire. The short life of the timber and the difficulty of building wooden towers to a greater height than 100 ft. are serious disadvantages.

A reinforced concrete tower on the other hand requires no upkeep so far as the shell is concerned, being practically indestructible; it is proof against fire and may be constructed with perfect safety as high as desired.

Cylindrical towers present a difficulty, for as soon as the diameter reaches a certain figure the air which enters through the openings provided for that purpose along the periphery of the cylinder, near the ground, is distributed very unequally throughout the area of the cylinder. The fresh air is warmed up immediately it enters, and has a tendency to rise vertically instead of going towards the central part; the small quantity of air which may reach the centre is too warm to be really efficient. The hyberbolic reinforced concrete shell is free from this disadvantage. It is quite smooth without any projecting pilasters, beams, or counterforts, either inside or outside, thereby securing an air circulation as regular as possible. The hyperbolic shape (*Fig.* 344) eliminates the shearing stresses, the construction of the shell becoming most economical. The great strength of a double curvature shell of this kind makes it suitable for resisting the most severe storms without having to provide internal bracings.

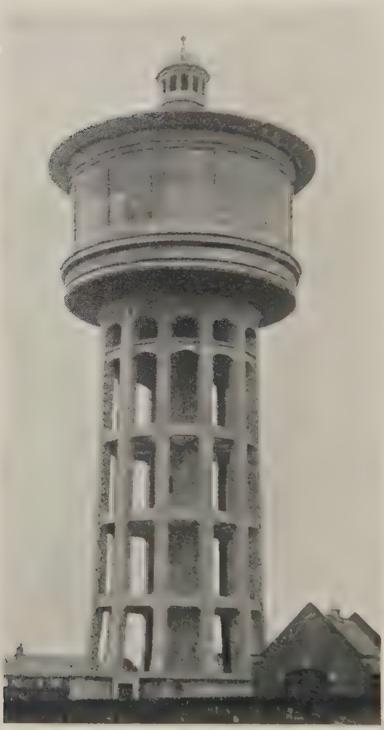


Fig. 341. 200,000-gall. Reinforced Concrete Water Tower at Ossett.

The monolithic nature and lightness of such a shell procure a great saving in the cost of foundations as there are no point loads, the loading being very uniformly distributed. For instance, a tower approximately 100 ft. diameter and 125 ft. high produces less than 2 tons pressure per foot run at the base, including that due to the wind.

Reinforced concrete hyperbolic towers can be made for all capacities. In practice, however, they are seldom built for less than 50,000 gallons an hour.

Generally speaking the capacity of timber cooling towers does not

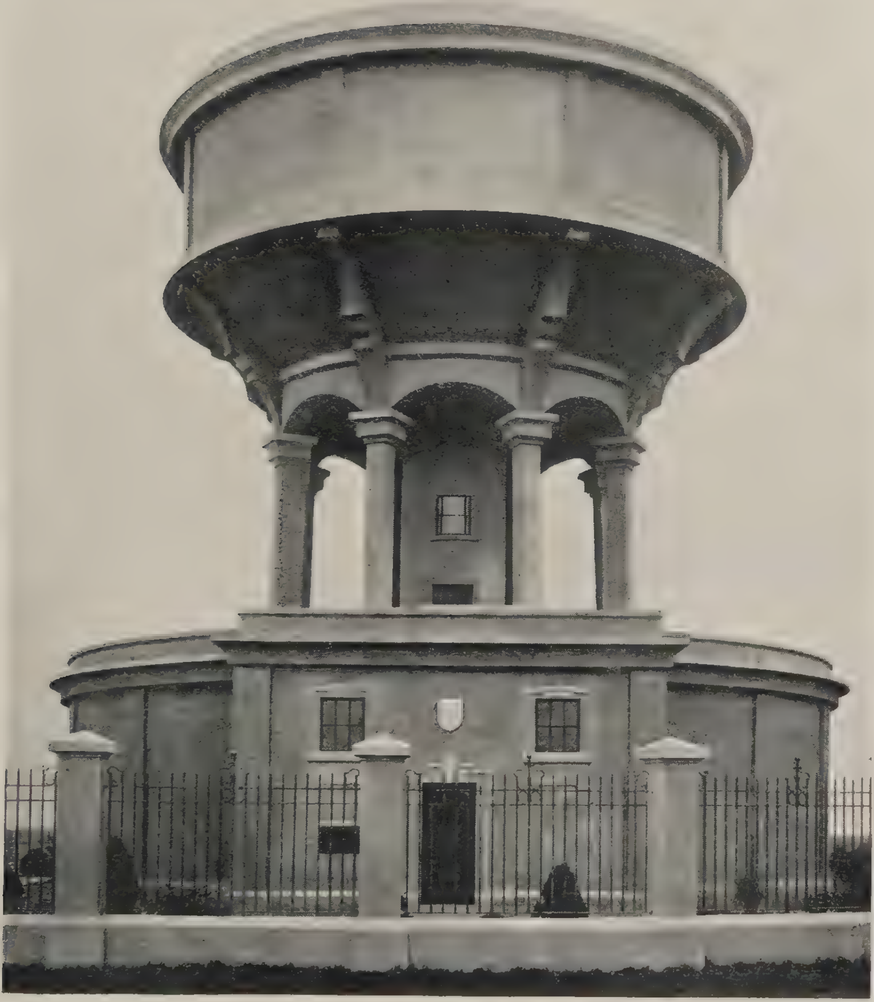


Fig. 342.—Reinforced Concrete Water Tower at Withernsea.

Reservoir at Ground Level, 300,000 gall.; Tank, 60 ft. high, 100,000 gall.

reach 100 gallons per sq. ft. covered. Hyperbolic cooling towers have brought about a marked advance in that respect. Cooling towers of this type have already been built at Liverpool and Leicester, and at the time of writing are under construction at Croydon for the Electricity Department.

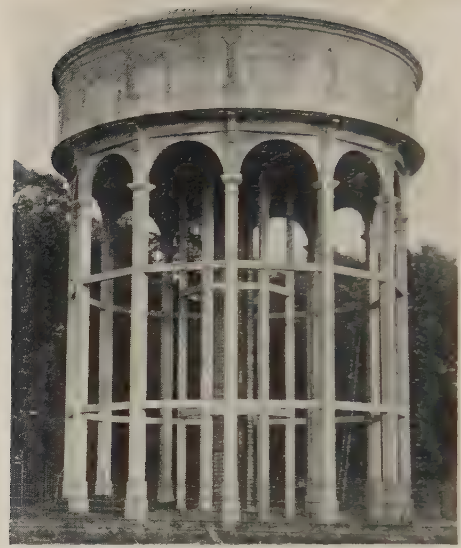


Fig. 343.—150,000-gall. Reinforced Concrete Water Tower at Bath.

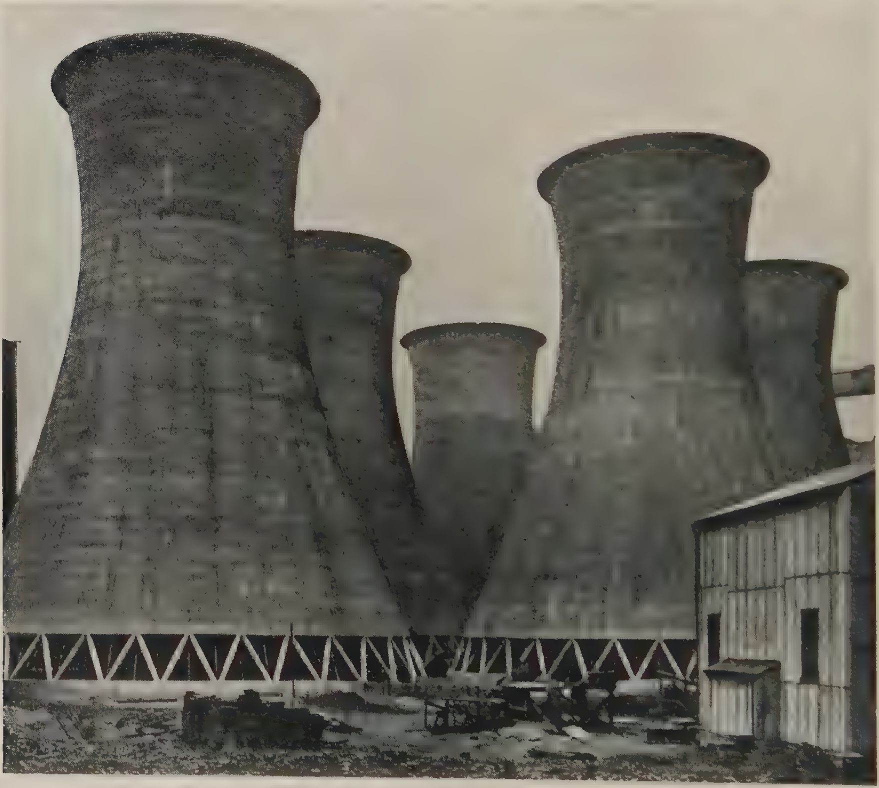


Fig. 344.—Reinforced Concrete Cooling Towers at Liverpool.

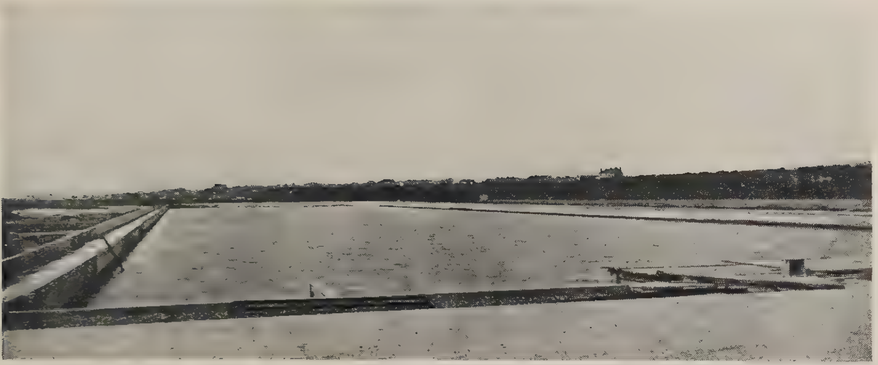


Fig. 345.—4½-million-gall. Reinforced Concrete Cooling Pond at Southwick.

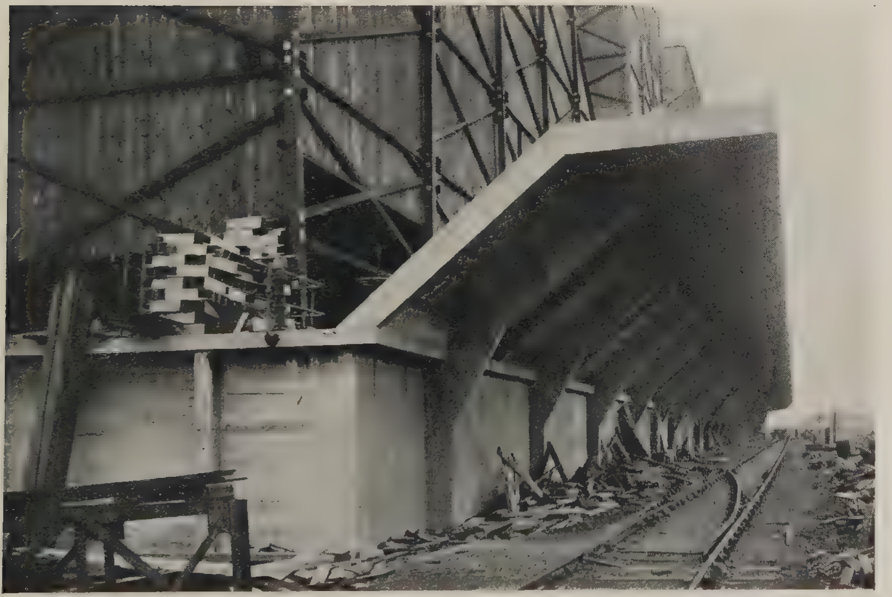


Fig. 346.—Screen Wall at Nechells Power Station.

Concrete in Mines

A mine gallery lined with concrete is illustrated in *Fig.* 347, pre-cast concrete slabs being used for the purpose. In this system the supporting tube is divided into a series of independent rings, and designed upon the principle that the greater the movement in the ground the smaller must be the rings. Each ring consists of concrete slabs laid against each other without mortar. To render an alteration in the shape possible, compression courses are inserted at statically important points. The slabs are made with holes near the outer circumference of the lining, and are reinforced during erection by a steel and concrete core. By this means dangerous pressure upon the internal edges is avoided without interfering with the working of the compression courses. With certain exceptions, "T" slabs are almost always employed; in comparison with a solid slab these possess the great advantage that with an equal transverse sectional area they give a greater strength of lining, or with a smaller sectional area an equal strength, greater solidity and a lower cost are attained and a greater power of resistance to pressure.

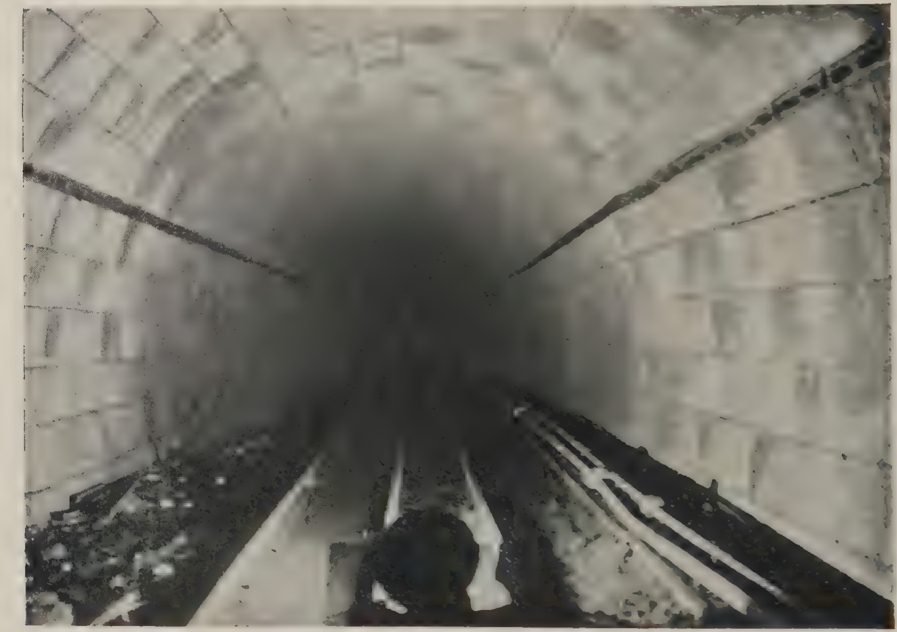


Fig. 347.—Concrete Lining to Mine Gallery.

The blocks can be lifted by one man and transported in any tram wagon,

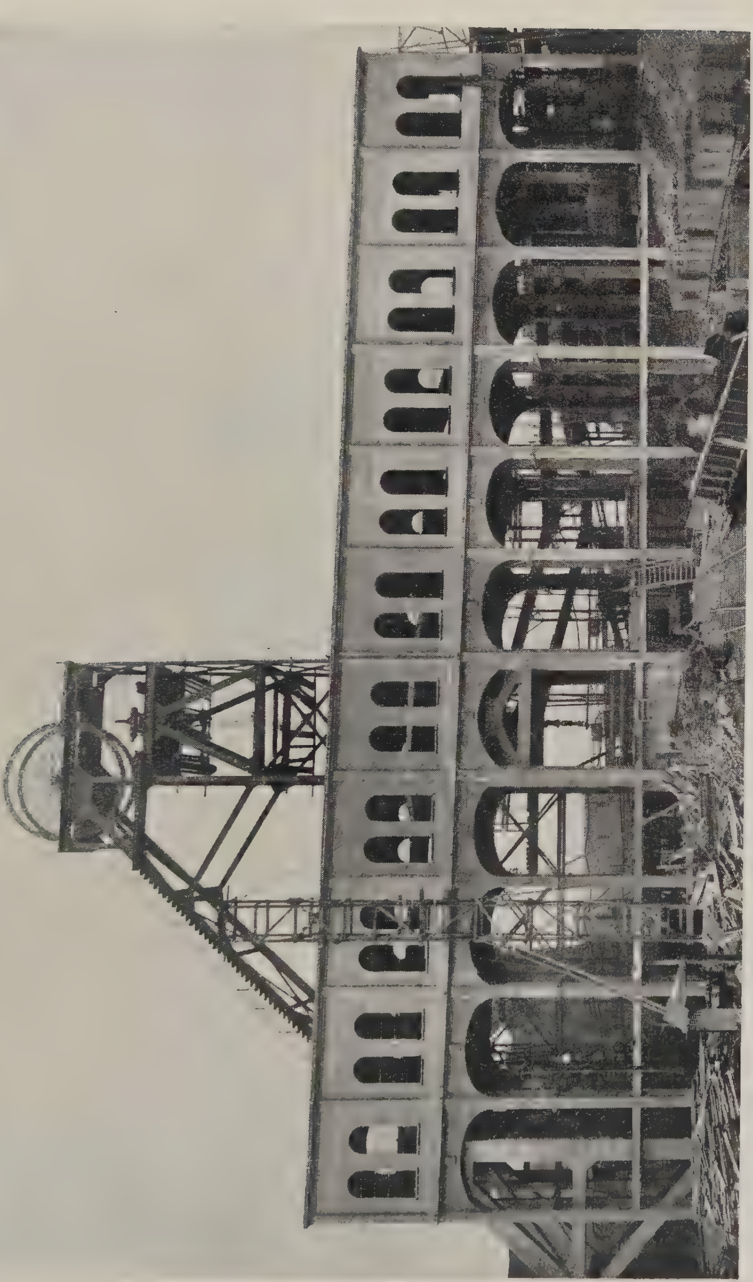


Fig. 348.—Reinforced Concrete at Bentley Colliery, Doncaster.

The forms are erected on the spot. No special arrangements are required, so that erection can be done without interfering with the normal working of a mine.

Gallery lining may also be carried out as described for tunnels.

Among other uses for which concrete is being increasingly used in mines may be included reinforced concrete pit props; these follow ordinary concrete post manufacture as described in Part VIII, the size and reinforcement depending upon the loads to be carried. The use of concrete for headgear and other colliery structures above ground is described later.

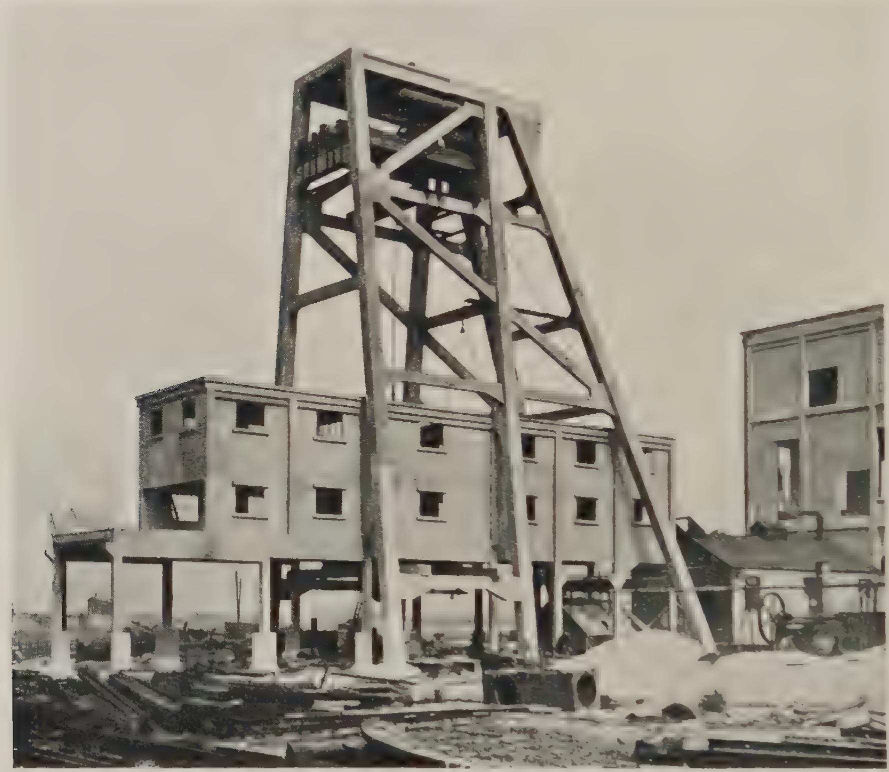


Fig. 349.—Reinforced Concrete Heapstead and Headgear at Bentley Colliery.

Pit-Head Gear

As already pointed out concrete is very economical where compression stresses are to be resisted, a condition which exists in the frames at pit-heads. For many years these frames were constructed of timber, a material which deteriorates rapidly, or of steel which requires a large expenditure for maintenance. The first use of concrete in the frames was merely as a protective agency which increased the length of the steel structure's life, a use which is neither sound from an engineering or economical view-point since concrete suitably reinforced can resist the stresses in the frame without using large steel sections. In addition, if the inclined members of a frame must be able to resist a direct thrust together with a bending moment caused by their own weight, it is much cheaper to provide and fix the extra steel required in a reinforced concrete member than in a structural steel one.

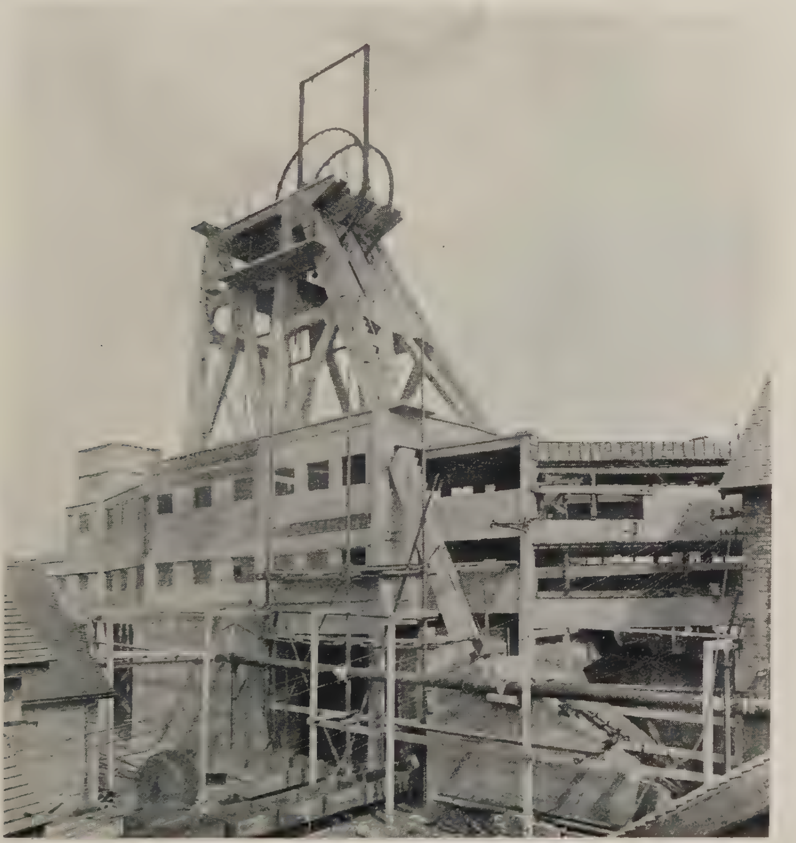


Fig. 350.—Reinforced Concrete Headgear, Heapstead, and Gantry at Arley Colliery.

The usual type of head-gear erected in Great Britain is the **A**-frame with one set of vertical and one set of inclined legs. Both sets may be battered if the shaft is inclined. Owing to the height of the platform above ground-level the wind force acting on the side of the frame may be very great and adequate bracing of all the members is necessary. The more rapid the rate of winding the greater the height required in order to prevent overwinding. Practice varies considerably in the loads assumed in designing the head frame, the impact stresses being very difficult to estimate. These stresses may amount to several times the working load on the cable if the latter is loose and the load comes on it suddenly owing to the cage stopping and then dropping suddenly.

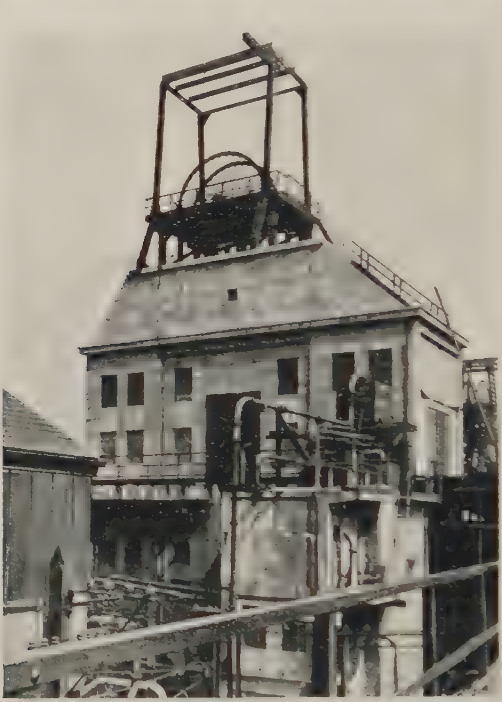


Fig. 351.—Reinforced Concrete Winding-Engine House at Denaby Main Colliery.

The construction of head frames is similar to that of other reinforced concrete frame structures with the exception that, owing to the steep inclination of one pair of legs, the column forms require to be stiffer and more rigidly braced than is usual for vertical members.

Some examples of reinforced concrete pit-head structures at English collieries are illustrated in *Figs.* 348 to 353.

Coal Washeries

The modern practice of requiring collieries to deliver coal to fulfil a specification is among the reasons which have led to the more extensive employment of grading, classifying and washing plants. There are several well-known methods of washing coal, but whichever plant is installed at the colliery it is the usual practice to erect the elevator pits, bunkers, and tanks in reinforced concrete. The usual process is to deliver the unwashed

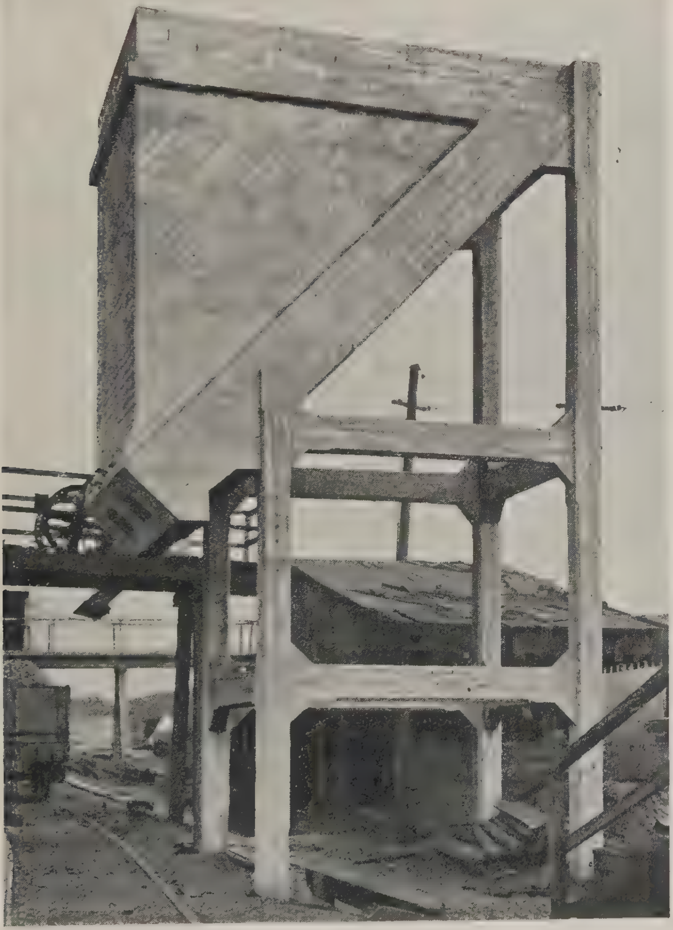


Fig. 352.—Reinforced Concrete Hopper at Brackley Colliery.

coal to a reinforced concrete elevator pit from which it is transported to the washery building where classification takes place. The dirty coal then passes through the washing machines after which it is elevated to the reinforced concrete hoppers from which it is drawn off as required. The water, containing the suspended coal dust and sludge, enters the reinforced concrete conical settling tank in which the sludge settles, the clear water being used again. The construction of reinforced concrete hoppers has already been described.

In systems using the conical settling tank (*Fig.* 354) the angle at the bottom is generally made 60 degrees and the lower portion of the cone is suspended from a circular beam supported on six, eight or more columns. It is, of course, necessary to provide "hoop-steel" reinforcement, in addition to the suspension steel, to prevent the cone bursting under the internal water pressure. Since the diameter of the hoop steel circle decreases as the water pressure increases the variation in the amount of steel at different depths will generally be small.

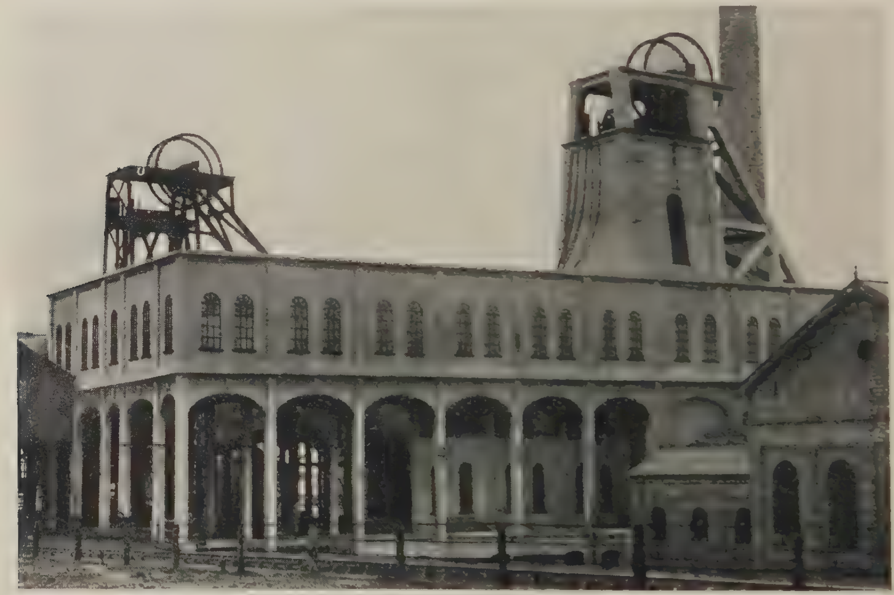


Fig. 353.—Reinforced Concrete at Bentley Colliery, Doncaster.

A light bridge is provided across the top of the settling tank. The spaces between the columns are filled in with reinforced concrete panel walls provided with steel sashes and doors, and form a pump-house.

Washery buildings should be strongly cross braced between the columns

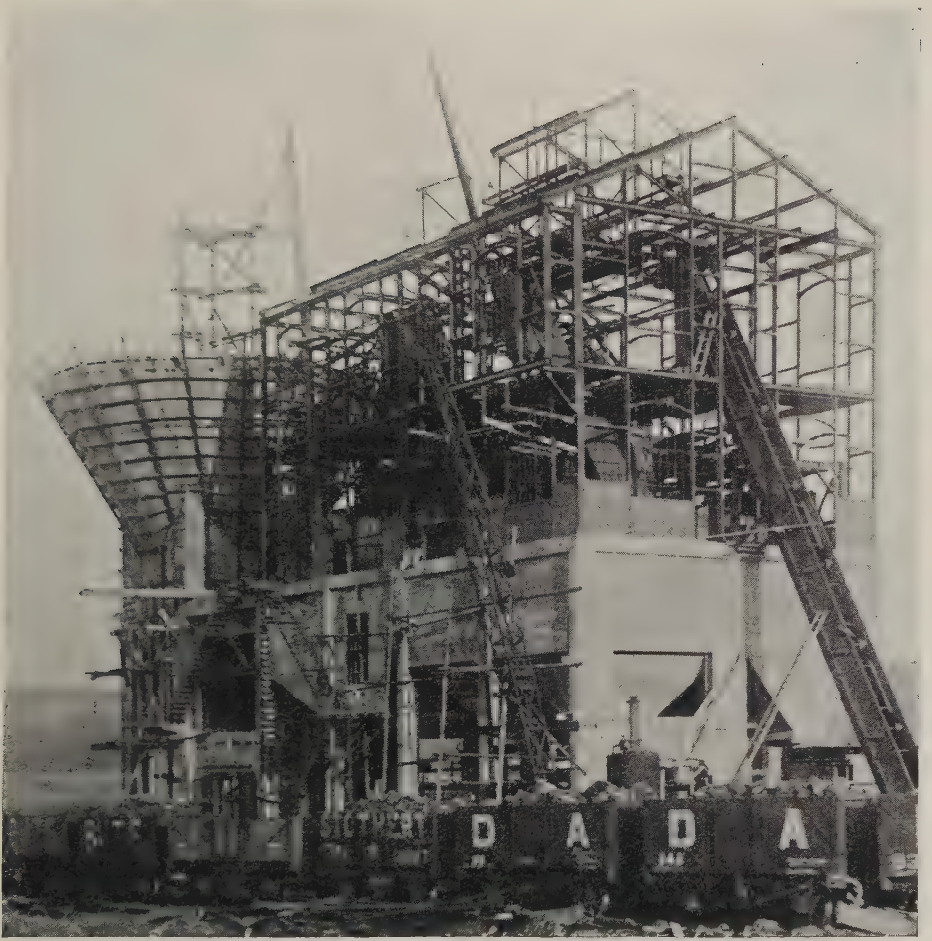


Fig. 354.—Reinforced Concrete Coal-Washing Plant at Hirwain.

where possible in order to prevent injurious effects arising from the vibration of the screens, etc.

Gantries

On account of its low cost of maintenance reinforced concrete has largely superseded steelwork as the material used for the construction of gantries at chemical and iron works, collieries, etc., where materials are handled in large quantities.

Two methods of handling materials on gantries are common, (*a*) using a

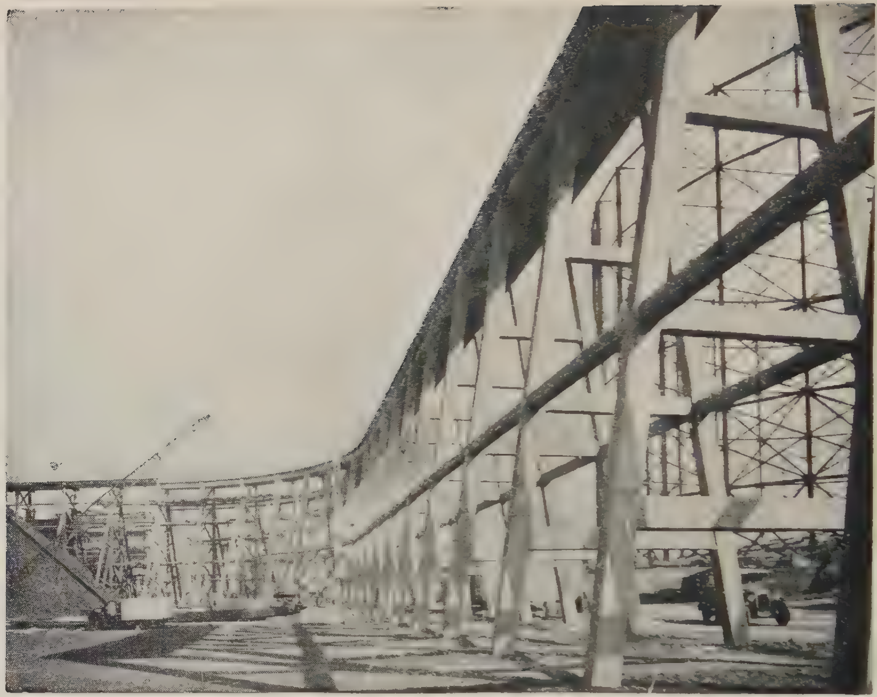


Fig. 355.—Reinforced Concrete Gantry at a London Gasworks.

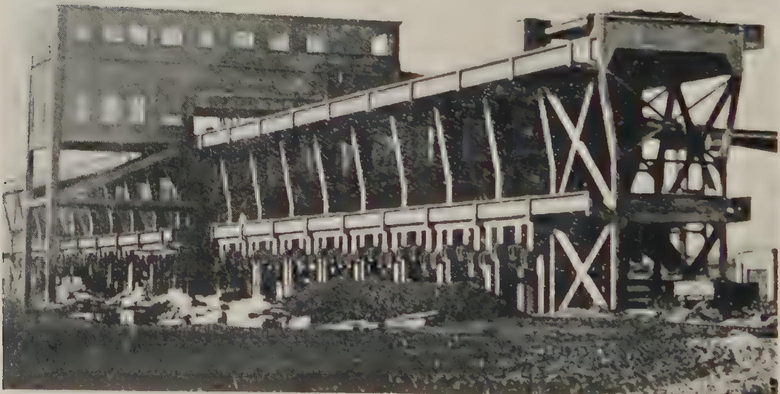


Fig. 356.—Iron Ore Calcining Plant, Irthlingborough, in Reinforced Concrete.

locomotive crane and grab which lifts the material from a pile, travels along the gantry and discharges its load, and (*b*) shunting a train of wagons, hauled either by a locomotive or a capstan, along the gantry from a siding and emptying each truck in turn into a hopper below the gantry. If the first method is chosen care must be taken to design for the racking stresses caused by the crane.

It is general practice to have a reinforced concrete railbearer immediately under each rail and to support the ends of these on a reinforced concrete capping-post joining the tops of the columns. Where possible the columns should be directly under the railbearers. The trestle is constructed with or without transverse bracing; if bracing be omitted the cross-beam must be well haunched at its junction with the columns, to resist lateral loading.

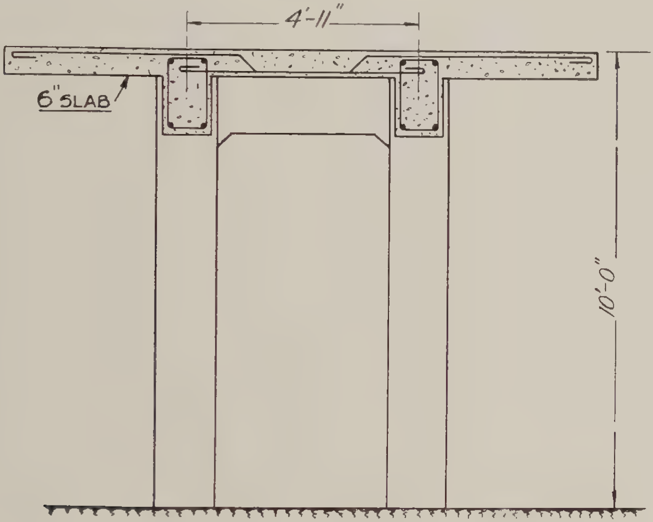


Fig. 357.

The decking (*Figs.* 357 and 358) may consist of a reinforced concrete slab between the railbearers with or without footways at the sides. In designing the railbearers it is most important to provide steel in the top surface to resist the negative bending moments caused in one span owing to the wheel-loads on its neighbours (*Fig.* 359). An impact coefficient must be allowed for in order to provide for vibration, etc. Expansion joints must be inserted at intervals and the columns duplicated where these joints occur.

Formwork.—The shuttering is similar to that in use for ordinary factory buildings, the only special feature being the provision of boxed-out holes for the holding-down bolts fastening the rail timbers to the decking. These boxes should be of tapered form so that they are easily released.

Concreting.—A tower is not generally suitable since the cost of shifting it when pouring a long narrow structure is high and it is preferable to concrete from jubilee skips on a timber trestled platform running parallel to the centre line of the gantry. Another suitable method is to use a locomotive crane running at ground level and delivering the concrete into a shallow timber box at the decking level close to the point where the concrete is to be put in position.

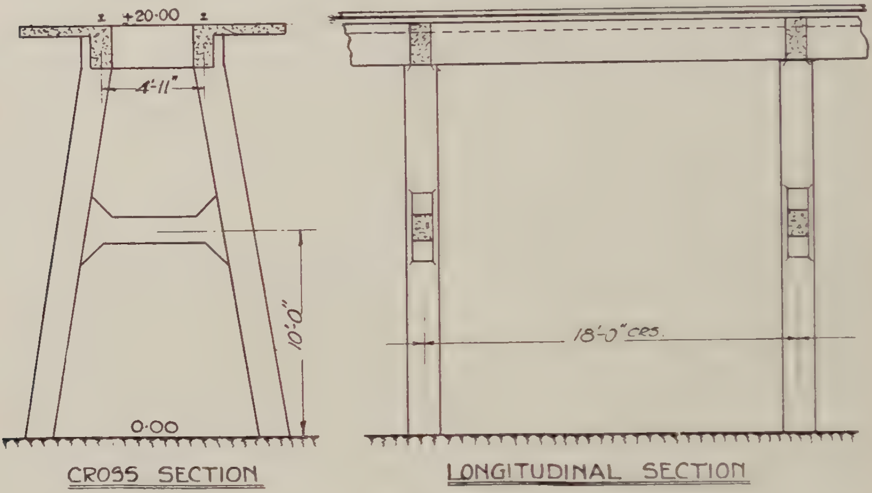


Fig. 358.

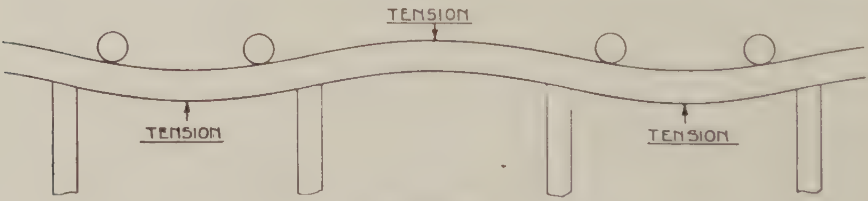


Fig. 359.

Concrete at Gas Works

In addition to its use for foundations to gasholder tanks and for the construction of tanks, below ground, to contain water, tar or liquor,

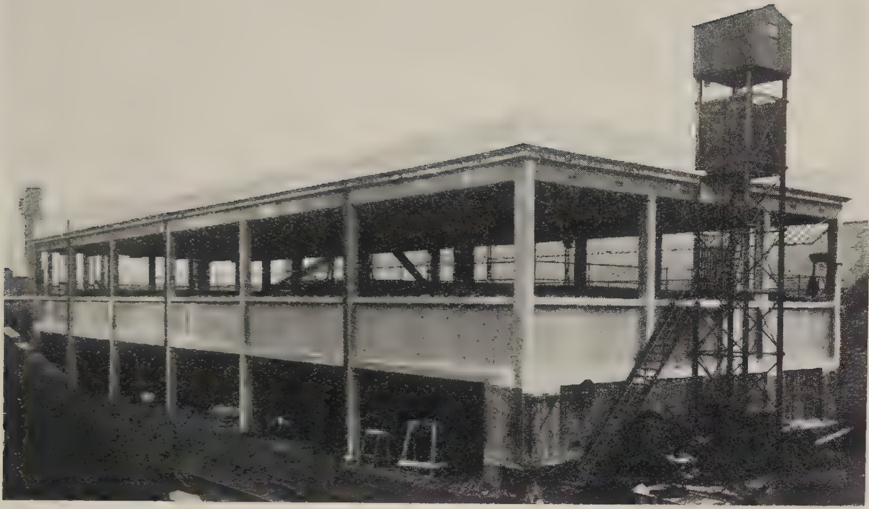


Fig. 360.—Reinforced Concrete Gas Purifiers at Crewe.

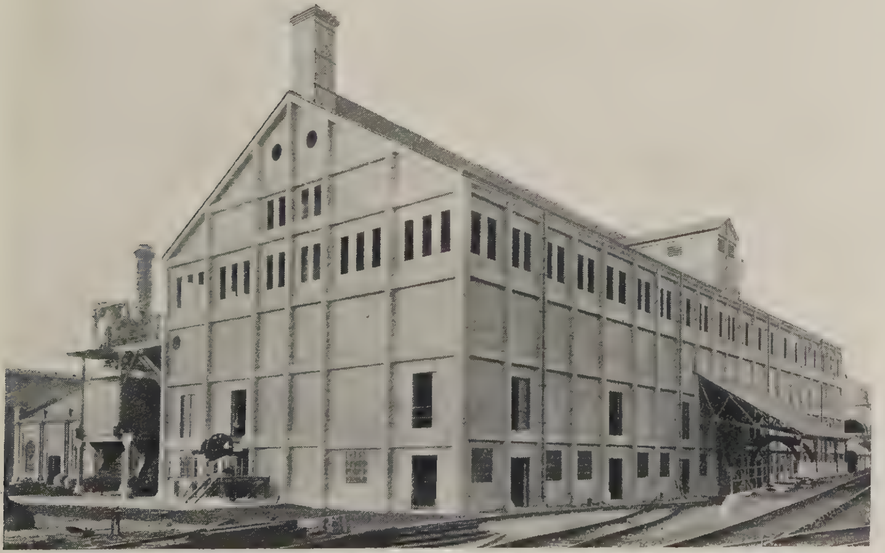


Fig. 361.—Reinforced Concrete Gas Retort House at Waddon, Croydon.

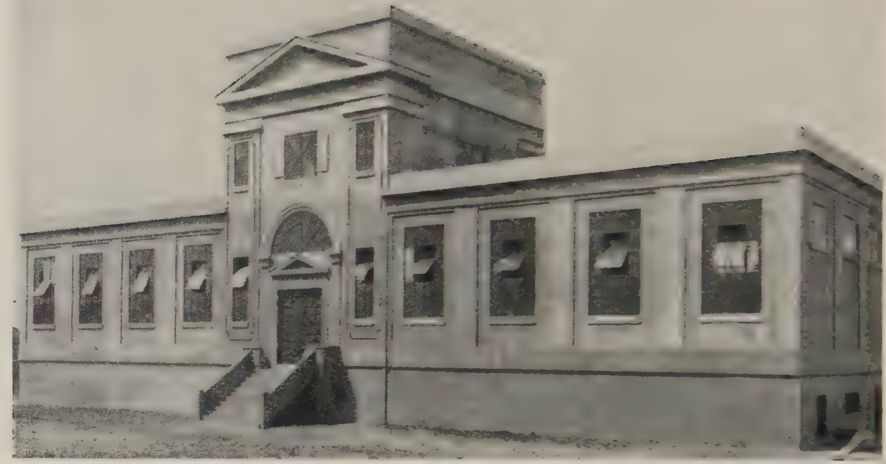


Fig. 362.—Reinforced Concrete Filtration Plant at Beckton Gas Works.

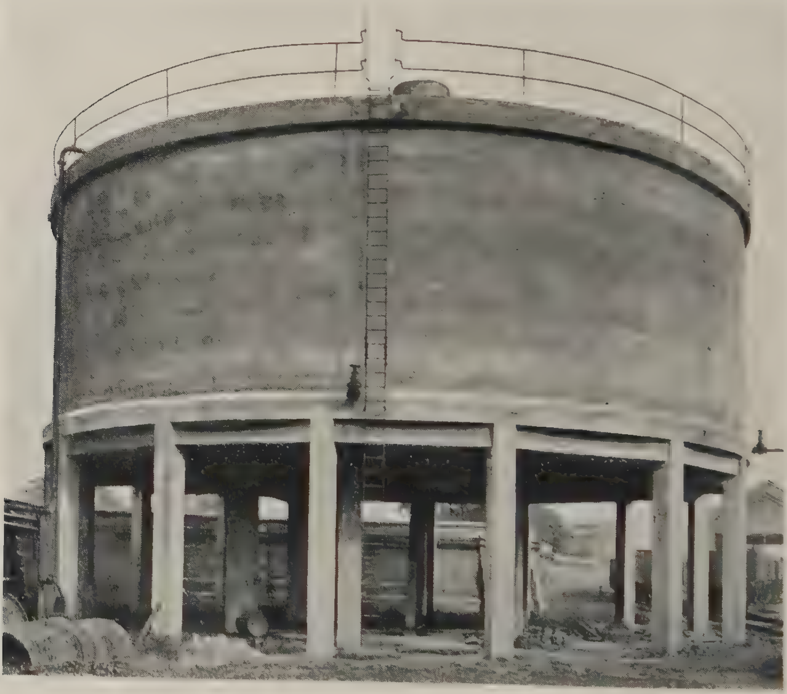


Fig. 363.—250,000-gall. Reinforced Concrete Tar Tank for the Aldershot Gas Co.

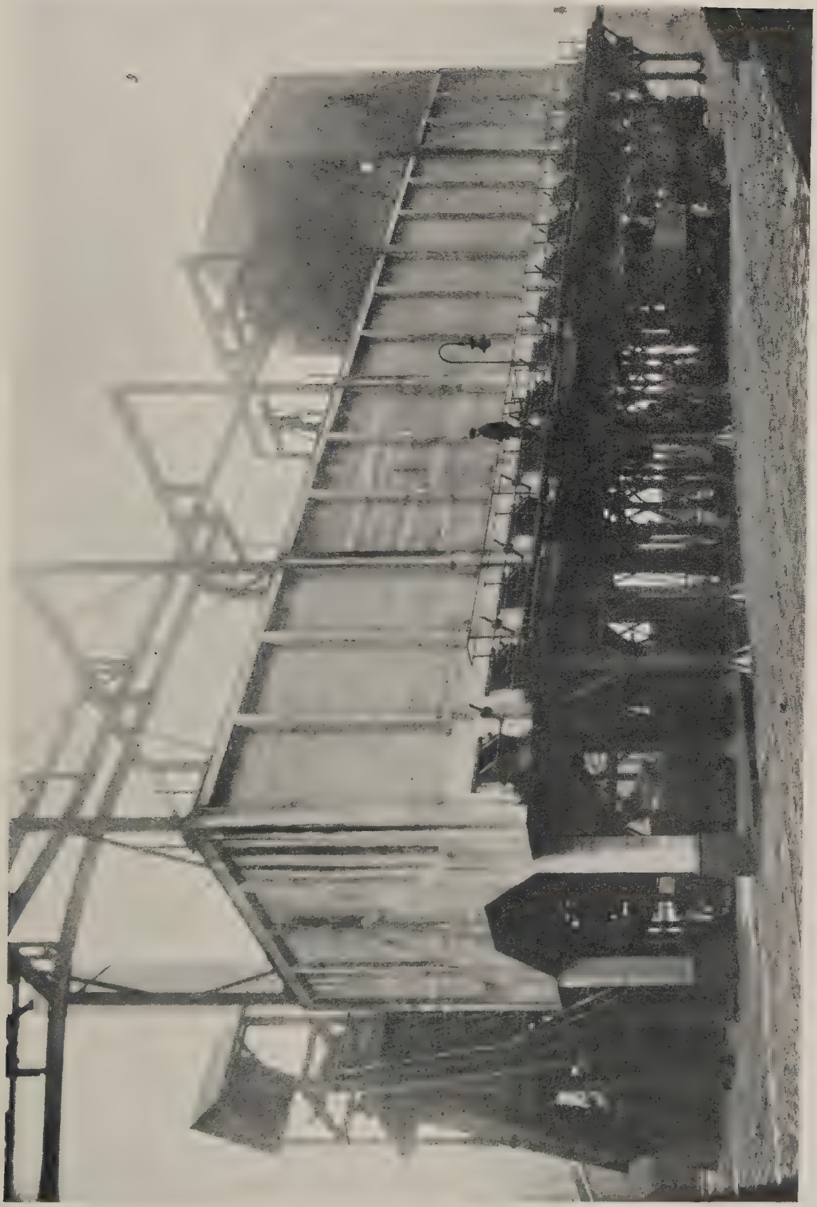


Fig. 364.—Reinforced Concrete Coal Storage Bunker, Bradford Road Gas Works, Manchester.

reinforced concrete has been extensively employed for raft or piled foundations to retort houses and slabs carrying purifiers, etc. The material is also economic in use for isolated foundations such as are required for trestles,

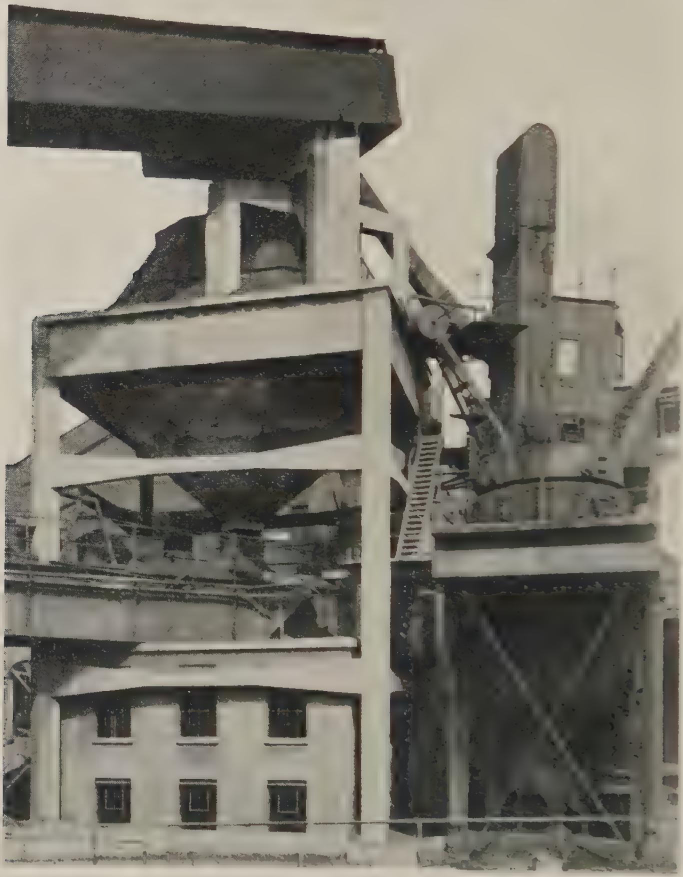


Fig. 365.—200-ton Reinforced Concrete Coal Bunker at Nine Elms Gas Works.

gas engines, gantries and chimneys and for the construction of retort houses, purifier houses, purifier boxes and filtration plant.

Many of these uses, and others such as in the construction of coal and coke bunkers and silos, conveyor and elevator pits, retaining walls, and chimneys are mentioned in other parts of this book under the appropriate headings.

Figs. 360, 361 and 362 show purifiers, retort house, and filtration plant at gas works.

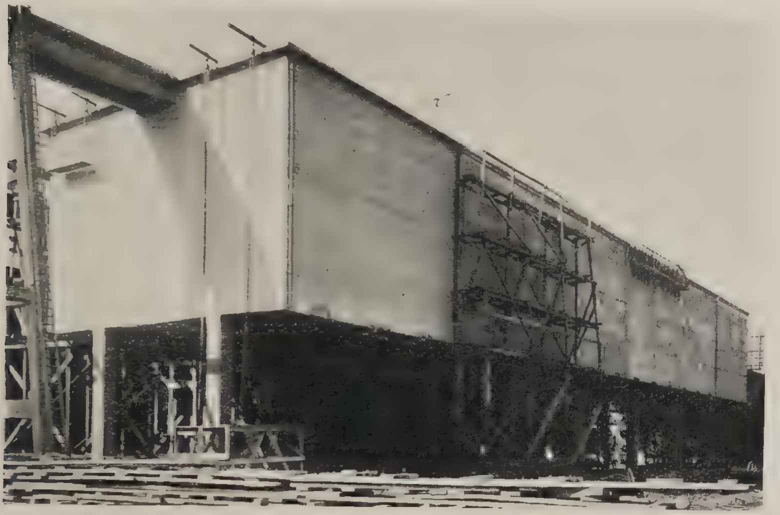


Fig. 366.—4,200-ton Reinforced Concrete Coke Bunkers and Gantry at a London Gas Works.

Reinforced Concrete Chimneys

The coefficients of thermal expansion of steel and concrete are practically the same so that the temperature of the flue gases in chimneys is without effect in causing any separation of the two materials. The temperatures in chimneys are generally in the neighbourhood of 500 degrees Fahrenheit whereas concrete has been proved to be unaffected by temperatures of over 700 degrees.

It is usual to introduce a fire-brick lining extending from two-thirds of the height to the full height and to provide for the expansion stresses caused by the difference of temperature between the inner and outer surfaces of the concrete. A 4-in. air-space between the concrete and the firebrick lining is advisable.

Each section of the chimney must be designed to resist the stresses caused by the direct load above and the bending moment due to the wind, and the whole structure must be carefully bonded to the foundation slab by extending the vertical steel bars sufficiently far into the latter. The intensity of the wind-pressure on a circular chimney may be taken as two-thirds

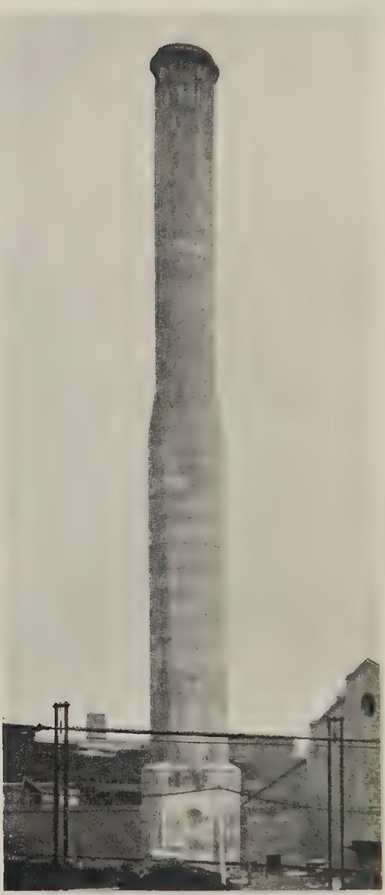


Fig. 367.—100-ft. High Reinforced Concrete Chimney at Fulham.

that on a flat surface. The vertical bars must be lapped for a distance equal to forty times their diameter since they are in tension. The horizontal rings of steel serve to prevent large cracks in the concrete and to resist the vertical shear, and for the former reason numerous bars of small diameter are preferable to a few large bars. A fairly wet concrete mix is usually specified for chimneys. Limestone aggregates should not be used. In modern construction the forms for chimneys are often jacked up from the vertical bars. In the upper portions of the chimney where the cross section of concrete is diminished the reduction may be made by stepping the inner side of the wall. Flue openings should be narrow in order not to cut away too much of the cross section of the concrete. The cost of scaffolding is usually a large item in chimney construction even when the modern steel type of scaffold is erected.

In addition to cast *in situ* chimneys pre-cast blocks of special shapes have been used for building chimneys. The vertical reinforcement is arranged within the joints between the blocks.

Examples of completed reinforced concrete chimneys are shown in *Figs.* 367-9.

Dams

The types of dams constructed for storage of water are three in number, (1) the gravity dam which, as its name indicates, derives its stability from its weight, (2) the arched dam of constant radius or constant angle, and (3) the reinforced concrete dam including those with plane upstream faces and those of the multiple-arch class. The choice of a type depends on the character of the site, the available materials and other factors.

The first-mentioned type is by far the most frequently constructed when the dam is high and the valley wide. Good impervious foundations are essential for dams. Provided that the bed of the stream consists of sound rock the dam may be built directly on this after cutting out any disintegrated parts and making chases to ensure that a good junction is obtained between the concrete and the rock. In order that the dam shall be stable and sufficiently strong, (1) the resultant at any joint must lie within the middle

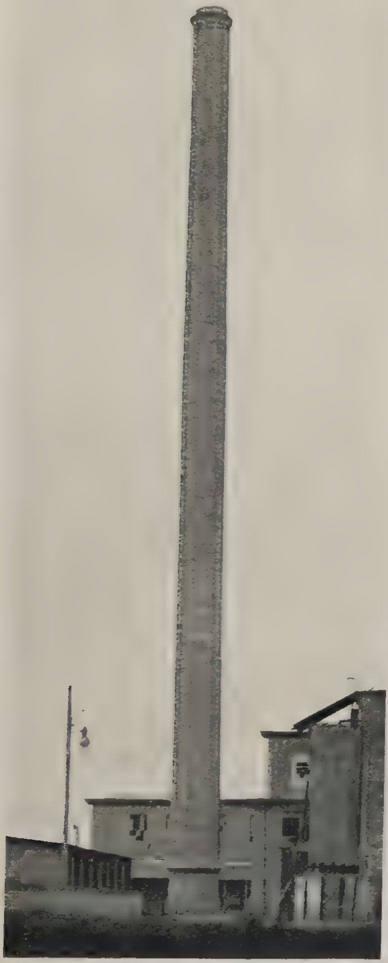


Fig. 368.

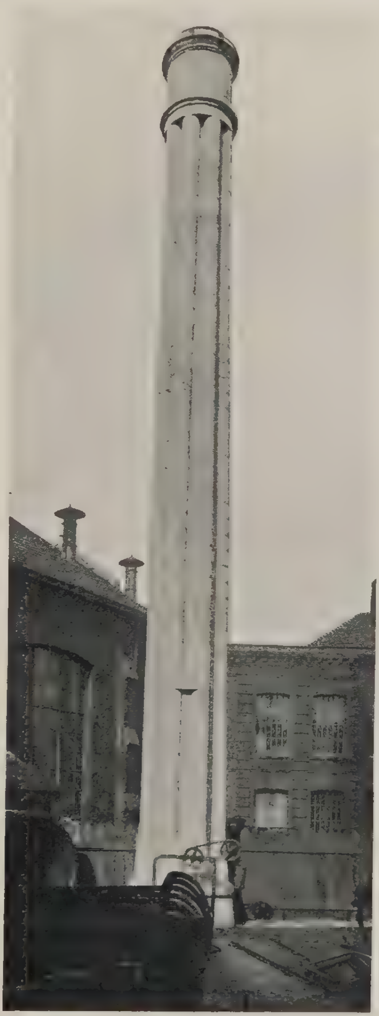


Fig. 369.

third of the section, (2) the maximum allowable pressure at the edge of any joint must be less than the working strength of the masonry or concrete, and (3) the angle between the direction of the resultant pressure on the joint and the normal to the joint must be less than a certain limit at which sliding would take place. The influence of upward hydrostatic pressure due to percolation of water under the dam must also be investigated. The conditions stated above must be investigated for the case where the reservoir is empty as well as when it is filled.

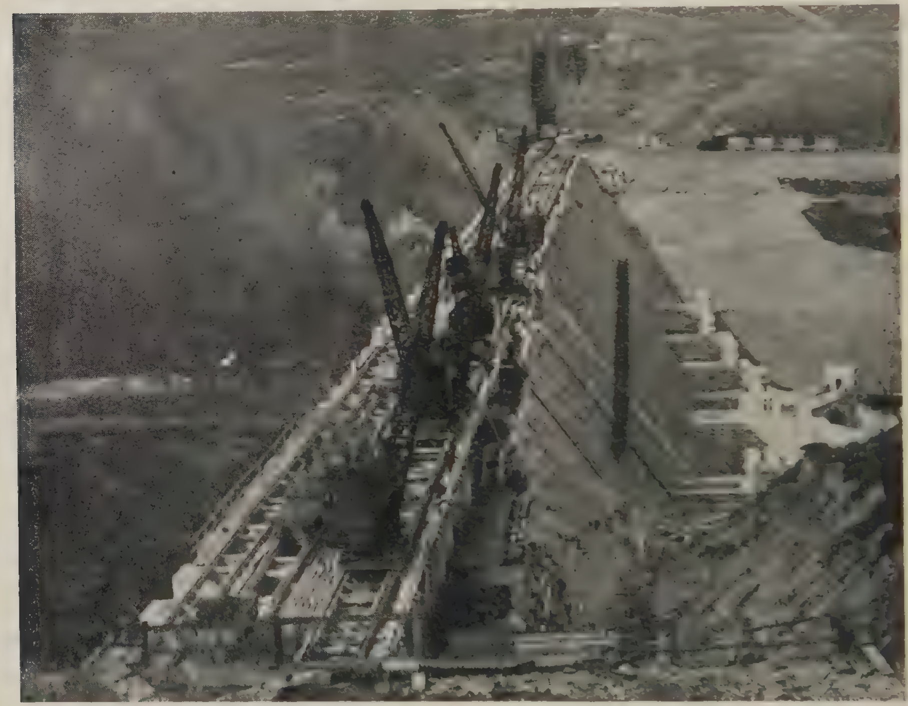


Fig. 370. Dam at Nidderdale for Bradford Waterworks Department (164 ft. high).

In narrow gorges with rocky sides the arched dam will often be cheaper than a purely gravity design even though its length is greater and the curved formwork is more costly. Its design is however very complicated since the arch is fixed at ground level as well as at its abutments.

The main features of the hollow dam (*Fig.* 371) are an upstream reinforced concrete slab making an angle of 45 degrees with the horizontal and spanning between buttresses in vertical planes. As a structure this type of dam is remarkably light and if the slab is inclined at 45 degrees to the horizontal the resultant water pressure cuts the base at the edge of the middle third. The effect of the weight of the dam is to bring the resultant inside this middle third if the downstream edge of the buttress is vertical. The soil pressure at the downstream edge of the foundation is therefore the maximum. In practice the downstream edge of the buttress is battered so as to make the soil pressure more nearly uniform throughout the length of the base.

The thickness of the sloping slab is variable from top to bottom, increasing as the head of water increases. The design is the same as that of a continuous slab uniformly loaded on all spans, but the shear strength of the slab must not be overlooked as this is often an important point. If it is required to keep the slab thickness low the steel may be arranged in such a way that the span of the slab is down the slope and that it is supported by beams running between the buttresses.

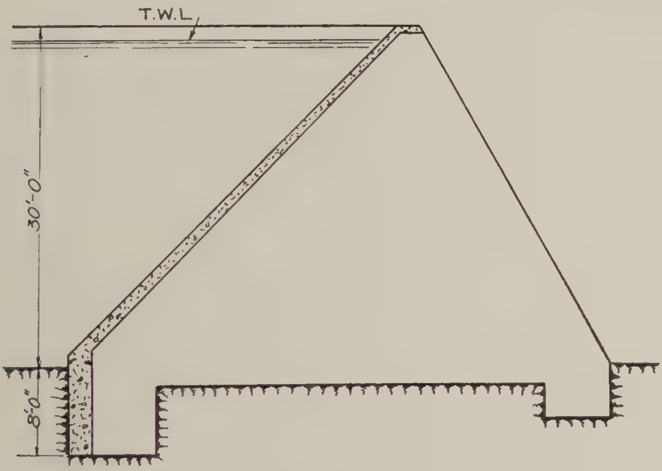


Fig. 371.

If an overflow or spillway is required the downstream edges of the buttresses may be connected by a slab curved to form the usual crest and apron at the top and bottom respectively. The buttresses are sometimes pierced by lightening holes with the object of saving concrete, but the cost of the extra formwork must be placed against that of the concrete saved.

Formwork.—The shuttering for this type of dam does not call for much comment; the main point is to use built-up panels for the sloping slab and the buttresses as there will be a large amount of repetition work. The slab will of course require a top form tied down to the reinforcing steel. The forms to the back of the sloping slab are often braced by round poles cut on the site.

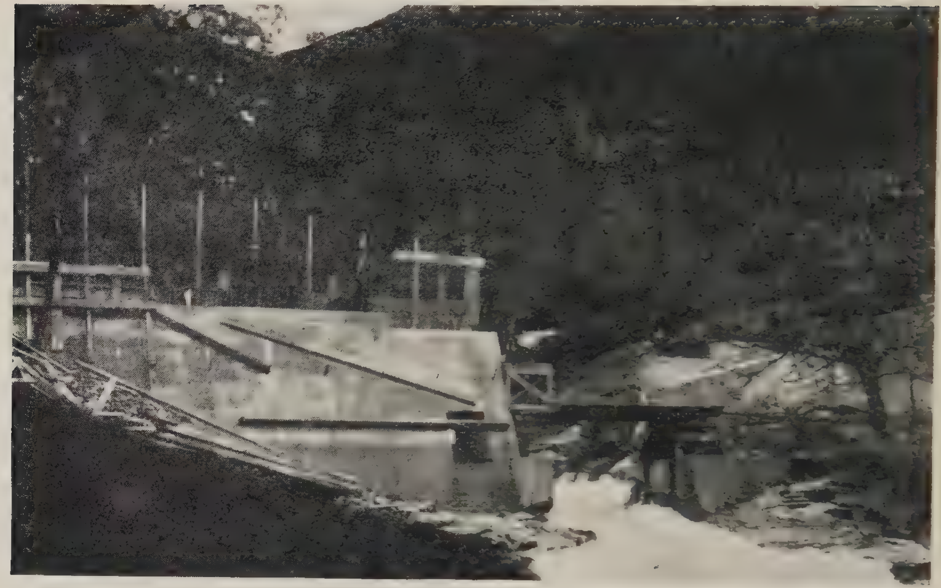


Fig. 372.—Concrete Intake Dam at Lochaber : Looking Upstream.

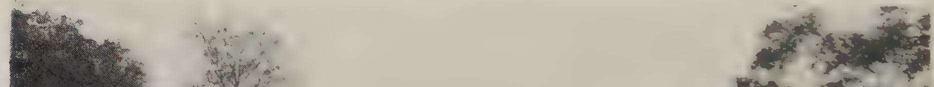


Fig. 373.—Concrete Intake Dam at Lochaber : Looking Downstream.

Concreting.—A satisfactory method of concreting, in the absence of a chuting plant or cableway, is to build a timber trestle parallel to the line of the dam. On this jubilee track is laid and the skips discharge into chutes leading to the formwork. The mixing plant is located, when possible, on one bank of the stream at a level higher than the crest of the finished dam.

Small Dams.—The construction of small dams under 6 ft. high, where provision has been made for preventing the water level rising above the top of the dam, may be undertaken as follows :

A temporary trench is excavated so as to by-pass the water around the dam while it is being built, or the water may be turned into a wooden trough in the middle of the bed of the stream, and after the wall each side of it is finished, the forms are erected across the opening, and made tight enough so that the water is at rest between them before placing the concrete. A trench slightly wider than the width of the base of the dam should be carried down about 2 ft. below the bed of the stream, or deep enough to reach good, hard bottom. The wall forms may consist of 1½-in. horizontal sheeting with 4-in. by 2-in. studs at 1 ft. 9 in. centres, 6-in. by 1-in. inclined braces should be nailed to the studs and to 4-in. by 4-in. pegs driven into the ground.

Valve Towers and Tunnels

When a gravity dam is constructed of concrete the valve tower may be incorporated in the wall and draw-off pipes carried through the wall at any level or point, whereas with earthen dams, in which the pipes pass under the embankment, the risk of unequal pressure and uneven settlement is very great and it is generally recognised that tunnel outlets clear of the end of the embankment slope must be adopted.

Canals and Locks

Owing to the increased cost of masonry and the difficulty in obtaining skilled stonemasons the use of concrete is becoming more general in the construction of lock walls (*Fig.* 374). The cost of curved entrance walls to locks is greatly reduced when they are built of concrete, the increased cost of the formwork for curved walls compared with plain straight walls being very much less than the corresponding increase where stones have to be cut to special templates and laid to a fixed radius. Concrete is peculiarly suitable as a material for inverts owing to the economy which can be realised with modern methods of placing mass concrete in thick sections.

In the ordinary section of canal, whether for barges, ships, irrigation, or power races the usual section is still one of earthwork with battered sides, but in places where puddle clay is expensive the core is often made of concrete, and the same material is extensively used as a lining to prevent erosion due

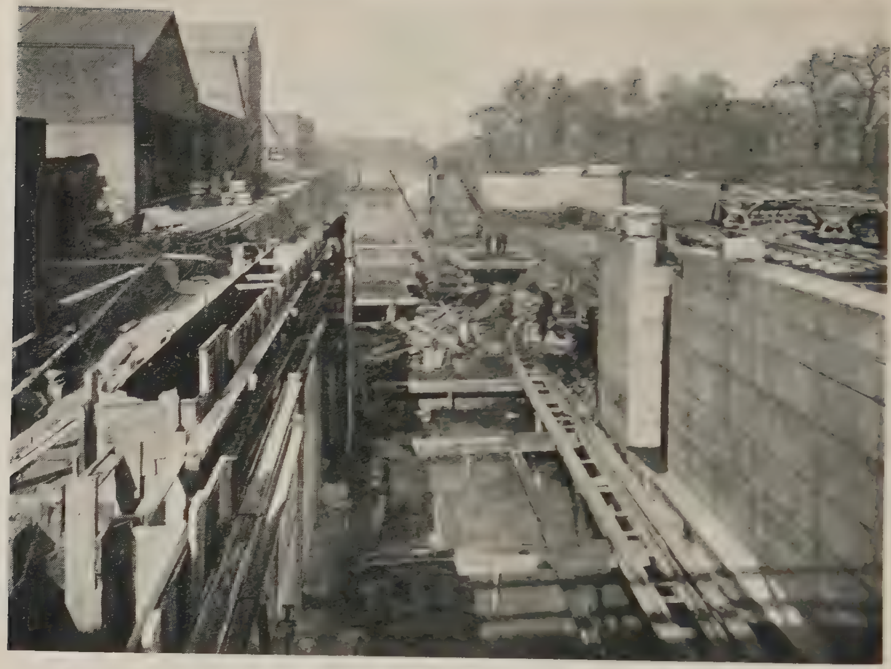


Fig. 374.—Grosvenor Canal Reconstruction in Reinforced Concrete.

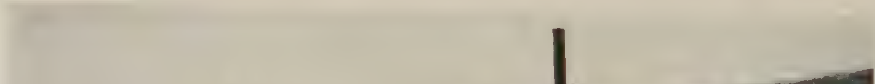


Fig. 375.—Concreting Canal Sides.

to wave-action of passing ships, or high velocity of the water. In such works a dense impermeable concrete is all-important. The required thickness of the lining cannot, of course, be calculated and depends on the velocity of the water and the probable height of the wave. The latter may be high if the wind blows in the direction of the flow of water in the canal.

The usual practice is to spread a layer of ballast over the surface of the slopes and lay the concrete on this in alternate bays, as described in the Part on Roads. Advantage is always taken of gravity in laying this concrete, that is, the mixer is kept at the level of the top of the bank or side of the cutting and chutes employed to distribute the concrete

Formwork is of the simplest nature since the side slopes are generally 1 in $1\frac{1}{2}$, 2, or 3 and top forms are seldom required. Batter boards are set up to mark the sloping edges of the panels (*Fig.* 375), and boards running in the same direction as the canal axis to define the top and bottom edges of the slab.

Reinforcement is required where the earth sides of the canal are not of uniform strength. The steel provides against the effects of unequal settlement.

Reservoirs and Underground Tanks

Design.—It has become almost standard practice among waterworks' engineers to specify reinforced concrete construction, especially in the case of roofed-in reservoirs of which there are a number at present in course of construction in the British Isles. One of three different types of roof may be used for such works. These are, (*a*) beam and slab construction (*Fig.* 376), (*b*) flat-slab (*Fig.* 377), and (*c*) concrete arch sheets (*Fig.* 379). The

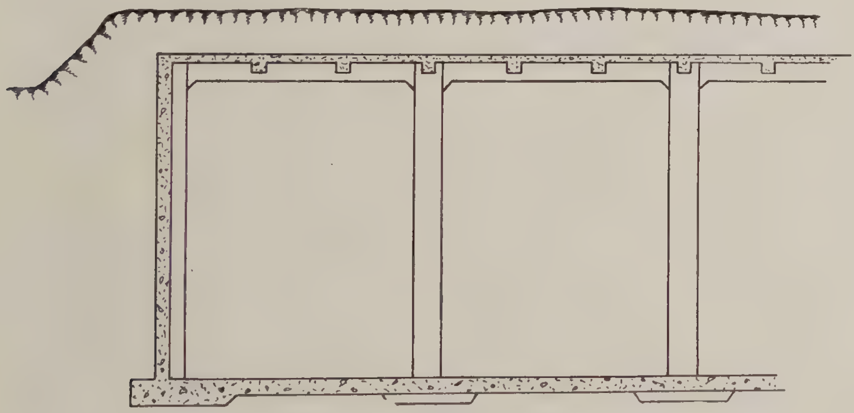


Fig. 376

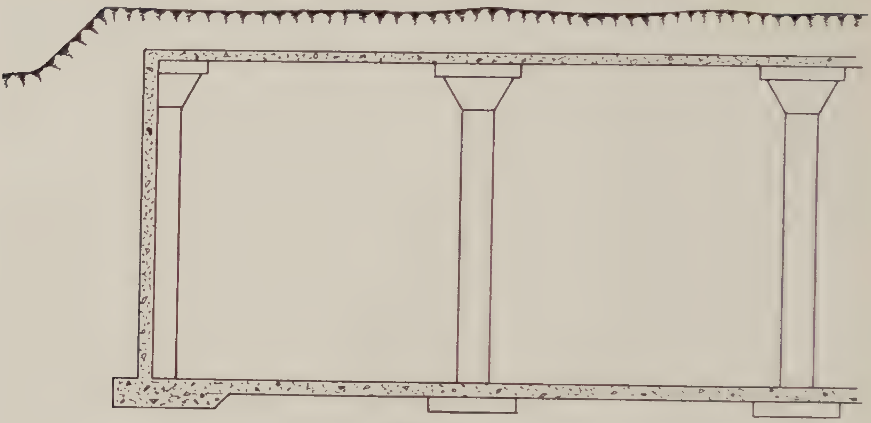


Fig. 377

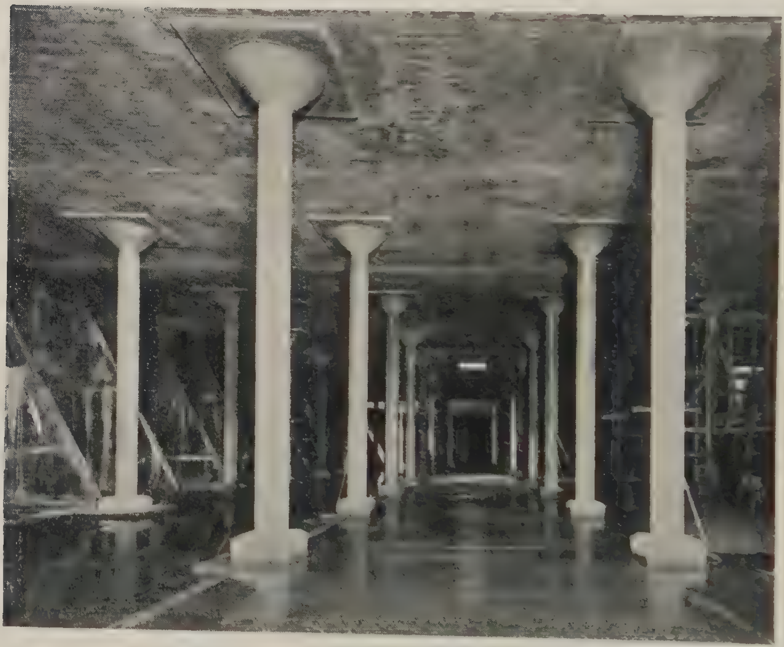


Fig. 378.—Ridgaling Reservoir, Nelson.

first two methods are more common in this country and in the United States, whereas the third is usual on the Continent and would appear to offer the cheapest solution of the problem, even though curved formwork is required, because the load is generally a dead one consisting of the weight of the arch sheet, and one or two feet thickness of soil.

Whichever type of design is decided upon care must be taken that the inlet and outlet pipes are not arranged in such a manner that a large volume of stagnant water is allowed to remain in any portion of the reservoir. This will occur if the pipes are close together in adjacent sides of a rectangular design. Pipes passing through concrete walls should always be fitted with puddle flanges.

Beam and Slab Construction.—If a beam and slab design be constructed there must not be any possibility of an air-lock occurring near the roof. This can be avoided by casting pipes of steel or other material in the beams so as to connect all the partitions formed by the roof, beam sides and water surface. The plan of the reservoir is often determined by the site condition and is generally rectangular or square.

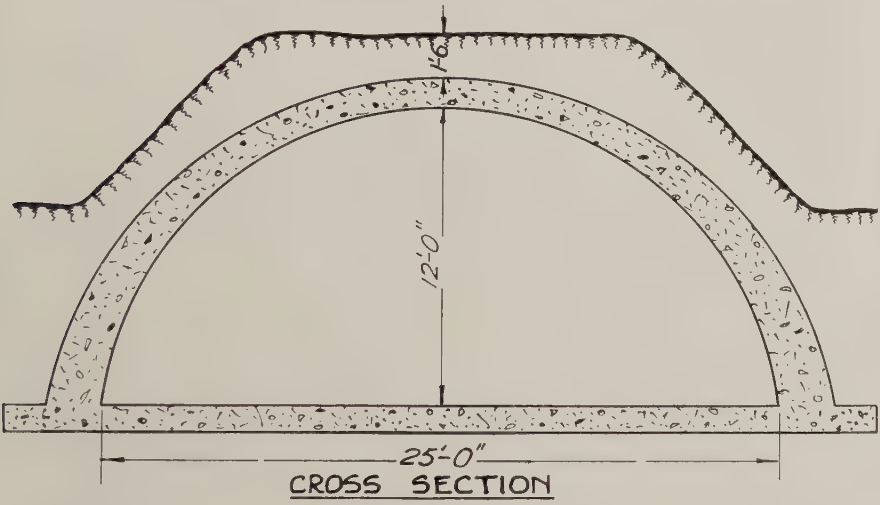


Fig. 379.

In beam and slab design the roof is rarely sufficiently stiff to give full fixation at the top, and the side and partition walls may only be taken as fixed at their lower ends, and free or partially restrained above. Low partition walls may be best designed in this way, the vertical steel being run into the base where the latter is thickened.

Since the load on top of an underground reservoir is rarely more than that due to a foot or two of earth the columns may be more widely spaced than is customary in ordinary building design. The external walls must be strong enough to take the active pressure of the earth when the reservoir is empty and the outward-acting hydrostatic pressure when it is filled,

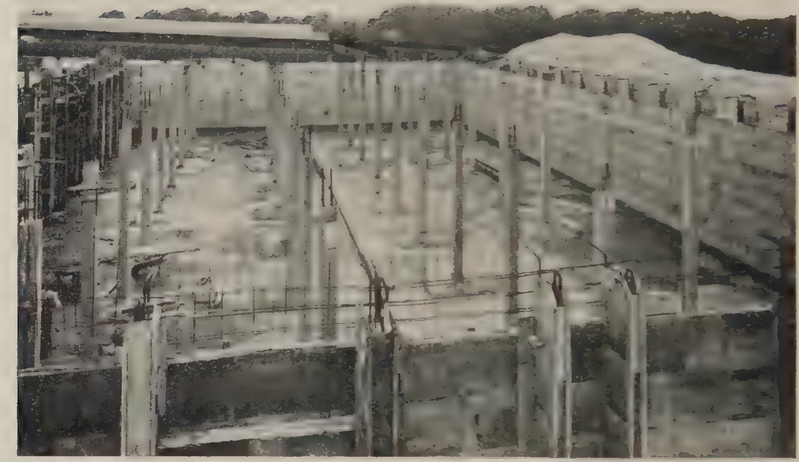


Fig. 380.—Epsom Reservoir during Construction.

consequently they must be reinforced on both sides. Partition walls also require double reinforcement since either side alone may be under

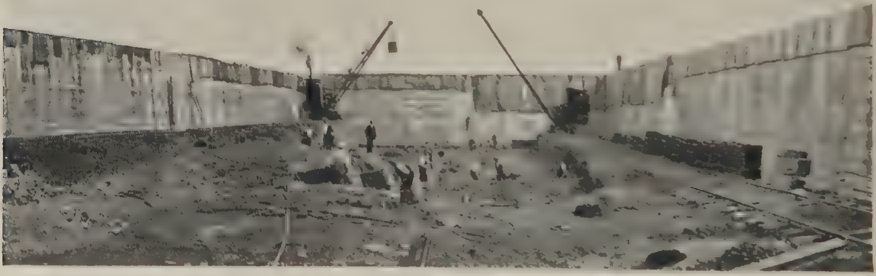


Fig. 381.—Heswall Reservoir during Construction.

full water pressure at some time. If the walls are very high they may be constructed to span either horizontally between pilasters or both vertically and horizontally. The walls may be either vertical or battered; the latter

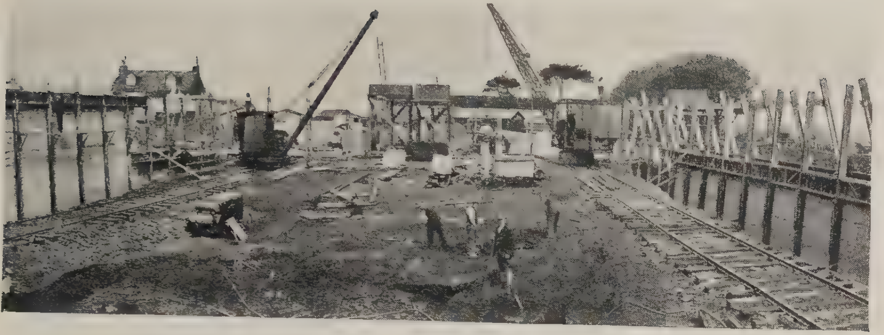


Fig. 382.—Burton Reservoir during Construction.

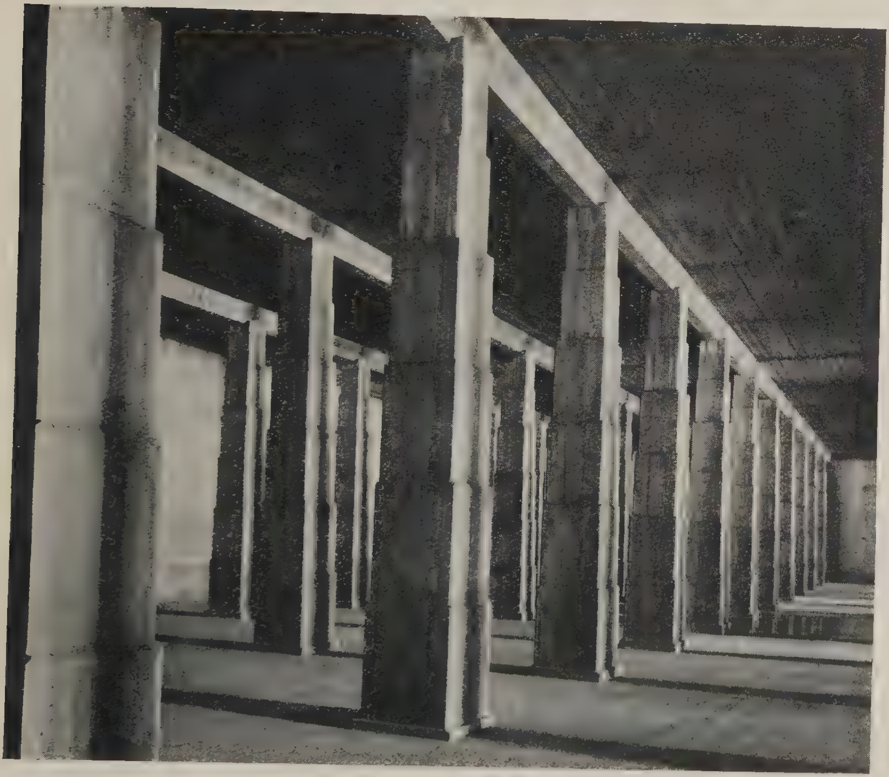


Fig. 383.—Interior of Springhill Reservoir.

method of construction saves concrete but does not permit of the use of climbing formwork and requires more reinforcing steel.

The wall footings must be sufficiently wide to prevent overturning, but the floor slab may be reduced to a minimum of 6 in. between wall and column footings if the ground is good and consistent in character. A less thickness is not desirable as it may result in leakage, and upward pressure may endanger the stability of the walls. It is good practice to extend the footing slab beyond the line of the outer face of the wall. This has two advantages: a ledge is provided to support the outer wall forms and studding and the balancing effect of the earth round the reservoir is added to the downward forces which prevent the empty reservoir being lifted if the ground is water-logged.

Expansion joints in the walls should not be spaced at more than 150 ft. apart.

A further use for reinforced concrete in waterworks is as a covering for existing open reservoirs, an example of which is illustrated in *Fig.* 385.

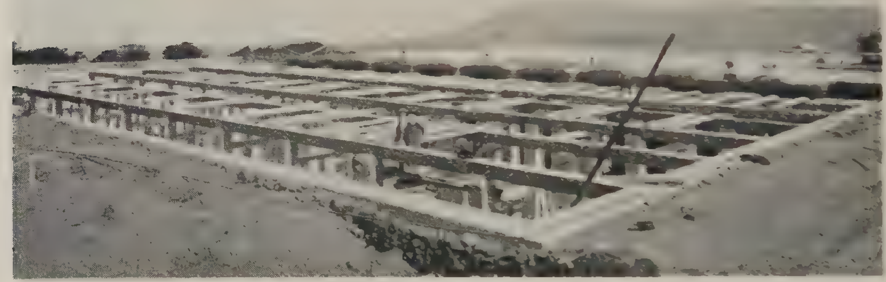


Fig. 384.—Spring Hill Reservoir during Construction.

Circular Tanks.—Circular tanks have the disadvantages that the steel detailing in the roof near the circumference is complicated if the flat-slab type of roof is employed and cracks may develop where the partition wall, if one is required, meets the side wall. The latter is very easily designed since it is similar to a cylinder under pressure, and, except for steel to resist the restraining moment at the base, may be reinforced by hoop steel only. The tensile stress on the equivalent concrete section should not exceed 70 lbs. per sq. in.

Tanks Below Ground Level.—Tanks entirely below ground level must be designed to resist (1) the pressure acting outwards when the tank is full, and (2) the pressure acting inwards when the tank is empty. They must also be sufficiently heavy to resist uplift if the ground is water-logged.

The safest method of design is probably as a cylinder under pressure

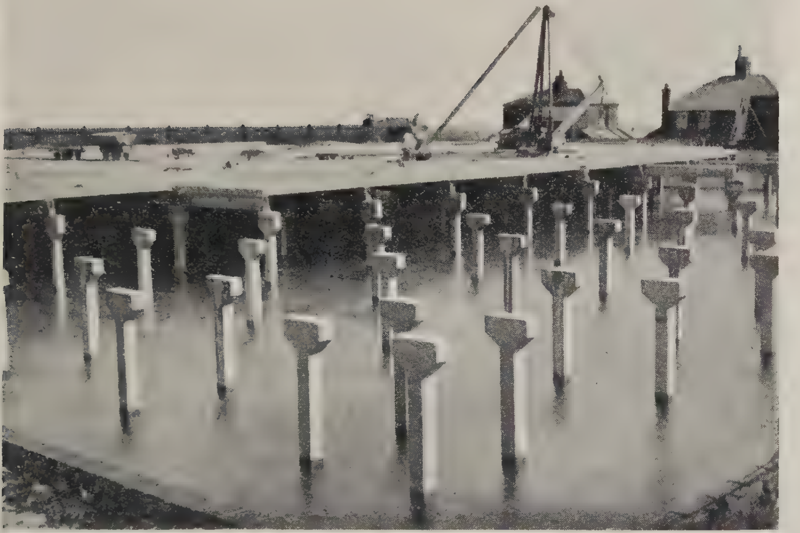


Fig. 385.—Reinforced Concrete Cover to Reservoir at Bridlington.

and fitted with a flexible joint between the wall and the base. It is however possible to allow for the fixation of the wall in the base and construct a tank monolithic with its base. In this case the lower portions of the wall are not free to expand fully under the hoop stresses in the wall, and a bending moment is therefore induced at the junction of the wall and the foundation

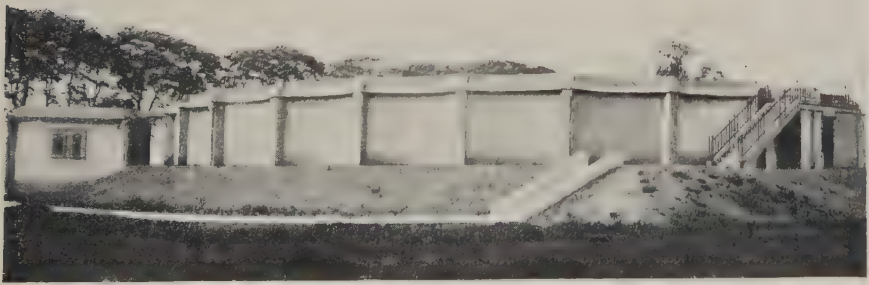


Fig. 386.—Reinforced Concrete Reservoir built for Wolverhampton Corporation.

slab. If the tank is only partly below ground level, the earth pressure acting inwards is reduced in magnitude.

The circular type of reinforced concrete tank is very often used for sumps, and tar and liquor storage at gasworks, in which case the roof must be designed to carry the loads caused by motor lorries passing over it. To avoid the difficulty of joining the straight partition wall to the side wall these tanks have been erected with two circular walls, thus dividing the whole structure into a central circular tank and an outer annular one.

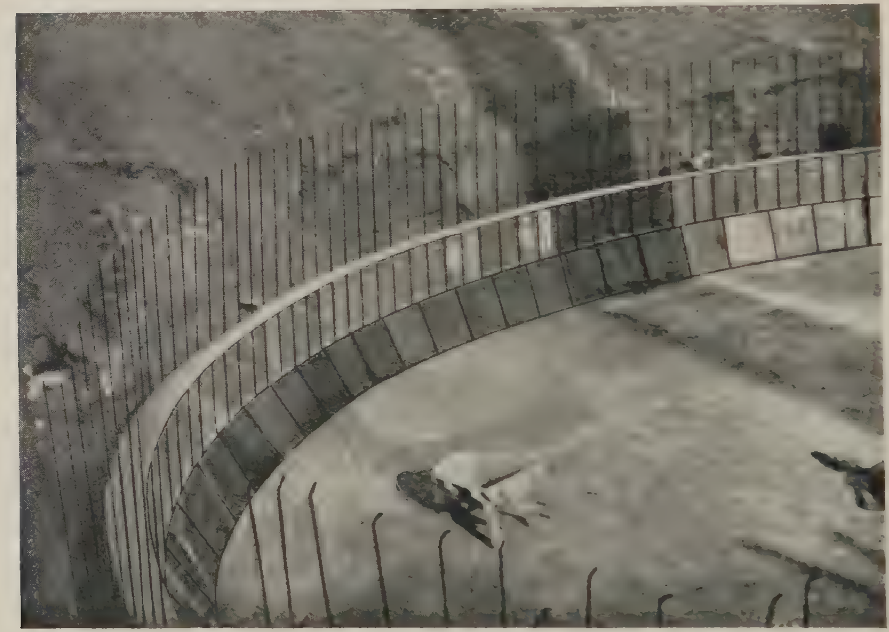


Fig. 387.—Circular Tank Construction.

Circular reinforced concrete tanks without roofs have also been used instead of steel for gas-holders (*Fig.* 388), and have proved eminently satisfactory even though the depth and water pressure is very considerable, a usual figure being 30 ft. corresponding to a water pressure of over 1,800 lbs. per sq. ft. This type of tank is built with a heavy top rib and pilasters to carry the stanchion loads.

Concreting.—Formwork may be of either steel or timber built up in panels. The former is particularly economical in labour costs for erection and stripping, and may be hired or bought outright. *Fig.* 387 illustrates the forms for the walls of a large reservoir. It is at present quite usual practice to pour the columns in one operation thus saving the cost of plumbing the forms several times. Such forms, however, require heavy bracing to resist the pressure of the liquid concrete, and careful tamping and filling to prevent segregation in the concrete.

For walls and floors a concrete mix in the proportion of 1 : 1½ : 3 is desirable and it is generally better practice to use a rich mixture than to employ waterproofing compounds. For the roof a 1 : 2 : 4 mixture will give ample strength. This should be laid with a slight fall from the middle to the sides. Concreting of the floor slab is commonly executed from a mixer at ground level discharging into concrete carts or skips at floor level, or by a complete tower and chuting plant which may also be used to pour the concrete for the columns and roof slab. As in other types of construction a layer of mass concrete spread over the site before pouring the reinforced concrete is useful to give a clean, hard surface to work on if the ground is wet. If the tank is altogether below ground a jubilee track may be laid round the walls, and the concrete distributed from this to wooden chutes reaching down to the wall formwork. If the wall is partly above ground a ramp may be constructed to enable the men to haul the skips up to the level of the staging from which the concrete is to be poured. In order to ensure that the walls will be watertight the tamping of the concrete must be carefully executed and all construction joints must be thoroughly cleaned before pouring fresh concrete in contact with them.

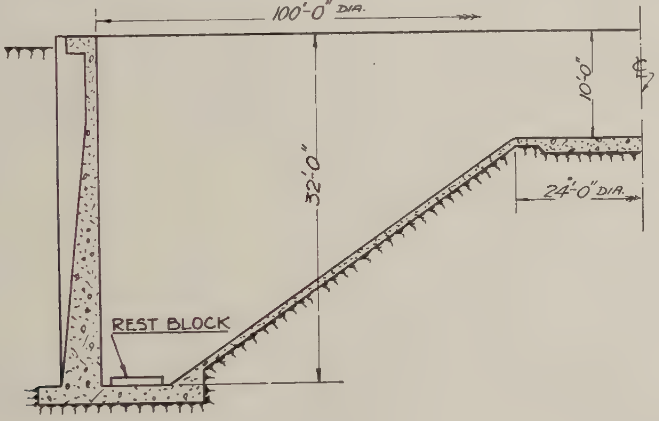


Fig. 388.

Swimming Baths

In selecting a site for an outdoor bath, a location should be chosen where natural drainage is good. It is highly desirable to have an ample supply of water at hand, whether it be from a stream, well, or public water main, to reduce the cost of the large water mains required for the bath supply. For the same reason the pool should be located so that it can be drained into a stream or sewer without an excessive length of piping. If the soil is not porous and naturally well drained, an adequate drainage system must be provided under the floor and footings so as to prevent damage by upward water pressure. The question of size for a proposed pool is a very

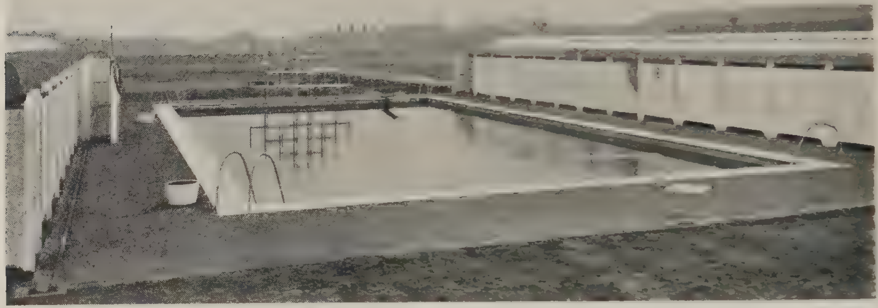


Fig. 389.—Reinforced Concrete Open-air Swimming Bath at Dudley Port.

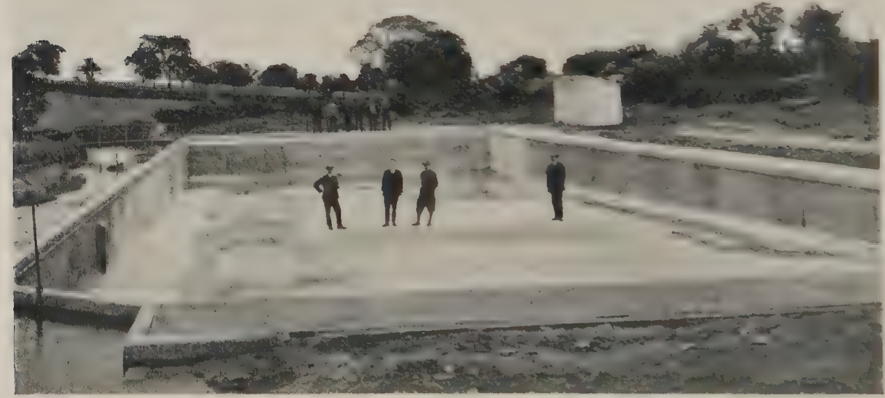


Fig. 390.—Reinforced Concrete Swimming Pool at Uttoxeter Recreation Ground.

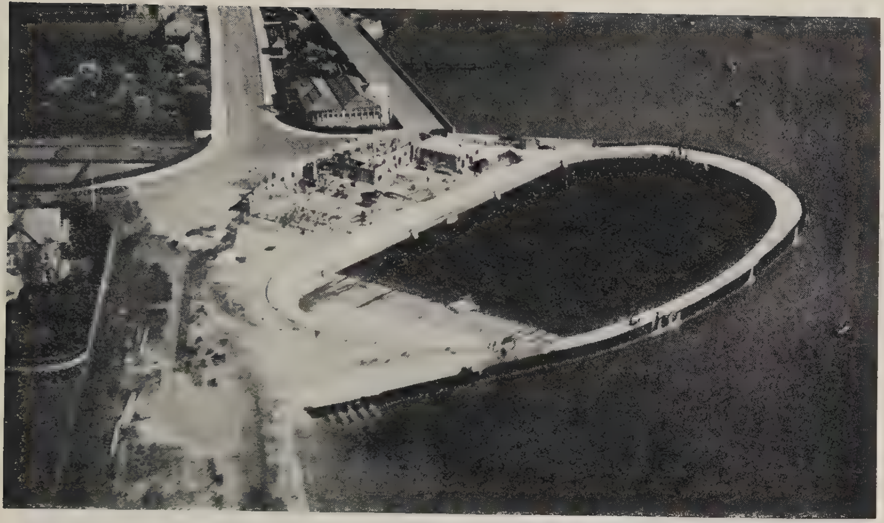


Fig. 391.—Reinforced Concrete Bathing Pool at Cleethorpes.

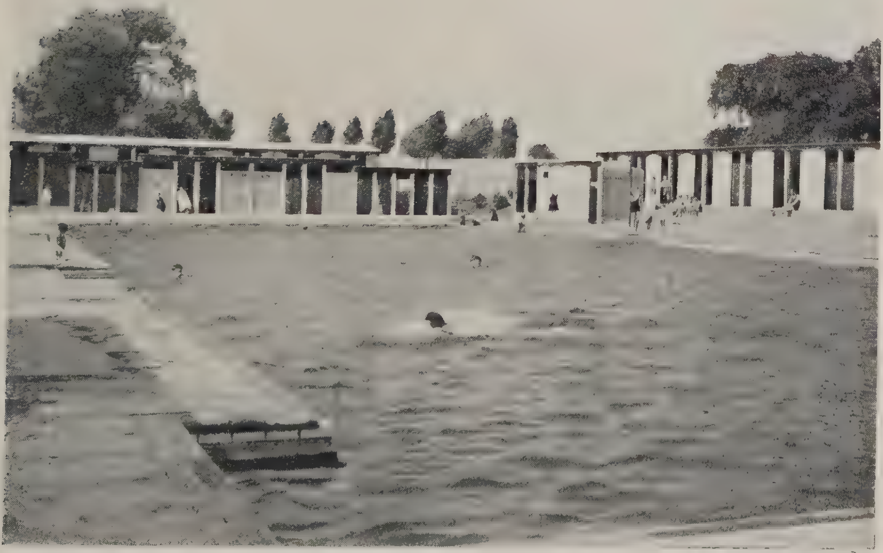


Fig. 392.—Reinforced Concrete Swimming Bath at Lewisham.

important one and merits considerable study inorder to arrive at a proper decision.

A very rough computation of the area required can be made by allowing a given area per bather for an estimated maximum attendance. In using this method one should allow approximately 20 sq. ft. of wading area per bather and at least 50 sq. ft. of diving area per bather, assuming that 80 per cent. of the patrons at any one time will be in the area having a depth of less than 4 ft. 6 in. Managers of municipal and commercial baths advise that about 75 per cent. of the area of the water should be 4 ft. 6 in. or less in depth, and that the remaining 25 per cent. of the bath should vary from 4 ft. 6 in. to about 9 ft. deep for diving.

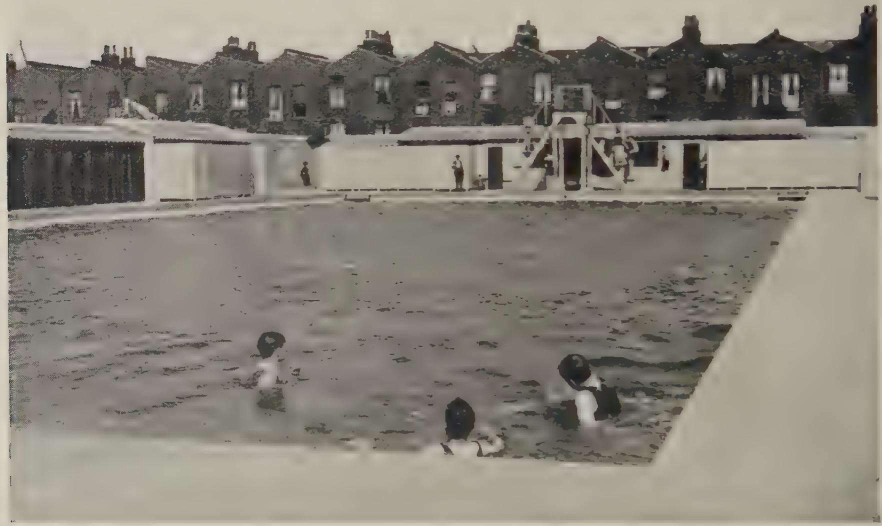


Fig. 393.—Reinforced Concrete Swimming Bath at Poplar.

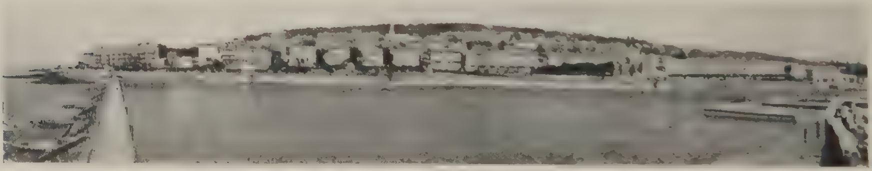


Fig. 394.—Reinforced Concrete Artificial Lake, Weston-super-Mare.

Rectangular baths are somewhat simpler to build than those having

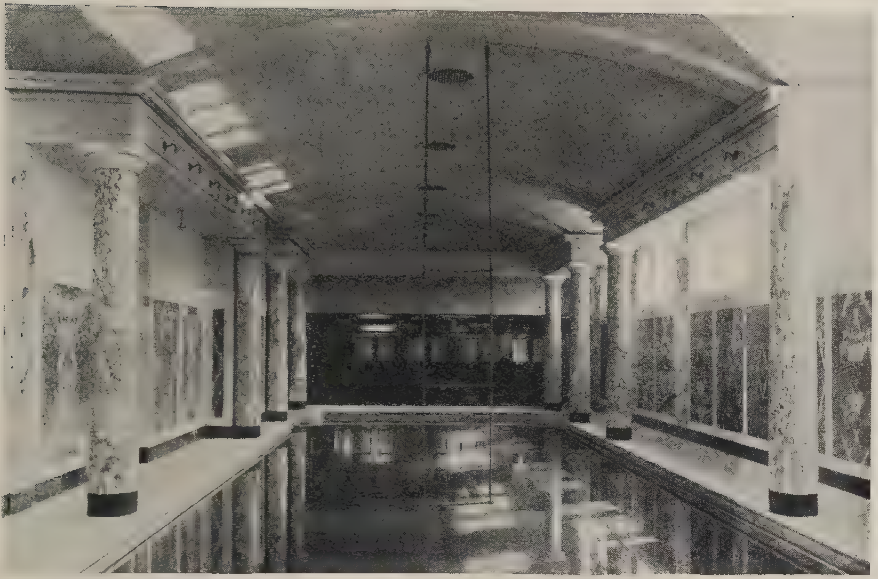


Fig. 395.—Reinforced Concrete Bath, Maiden Erleigh.

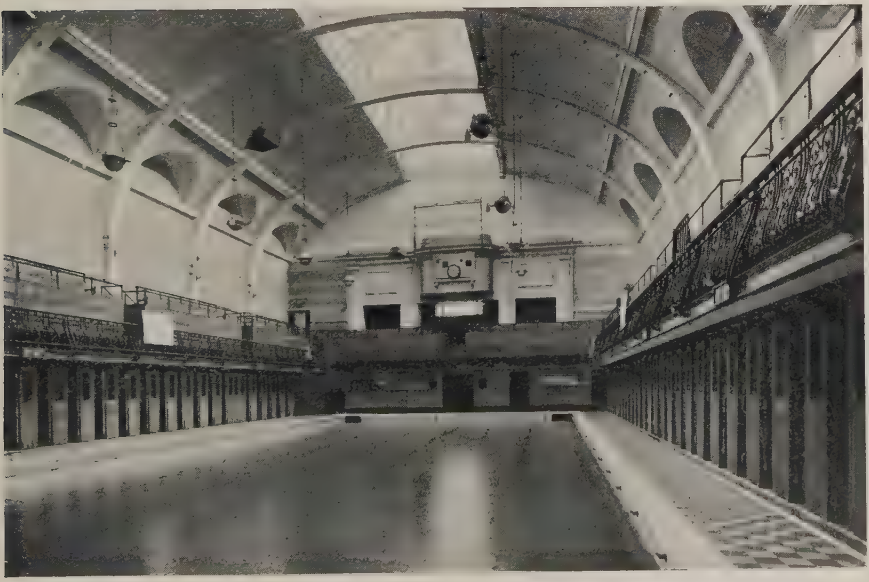


Fig. 396.—Reinforced Concrete Swimming Bath at Bermondsey.

curved sides, and for this reason baths of rectangular shape are more common than those of curved or irregular shape.

The walls may be of mass concrete or reinforced. In the latter case the size and spacing of reinforcement for any given section of wall are determined by the height of the wall at that section. The walls for rectangular baths are designed to resist the inward pressure of the earth when the pool is empty and the pressure of the water when the bath is full. Cracks in the concrete floor slab may be caused by temperature stresses unless the slab is properly reinforced and divided by expansion joints into sections having no dimensions greater than 30 ft. Expansion joints need not be provided in straight reinforced walls of swimming baths at intervals of less than 100 ft.

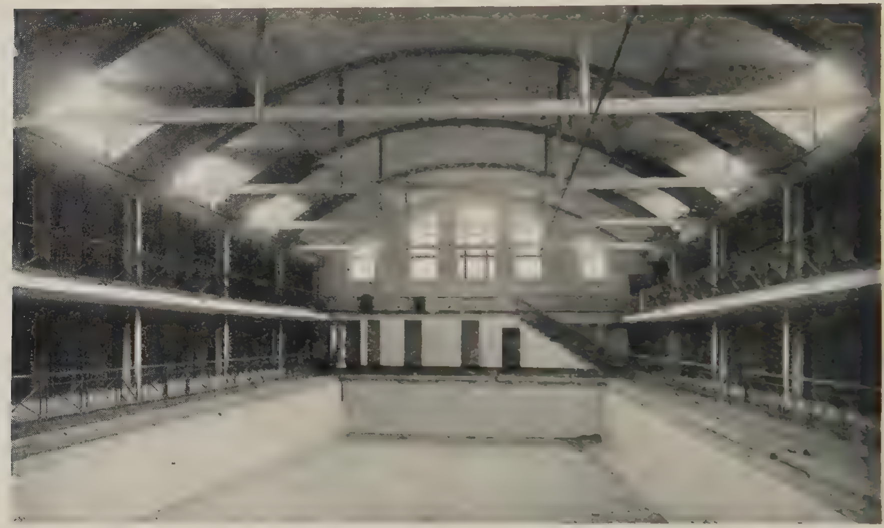


Fig. 397.—Reinforced Concrete Swimming Bath at Whiteinch, Glasgow.

For notes on the formwork required for the walls, see p. 145. The method of concreting and the construction is in all particulars similar to that used when building small tanks below ground level, already described in this Part.

Pumping Stations

A very usual method of obtaining a watertight concrete floor in a pumphouse is to pour inverted reinforced concrete arches between wall footings which are made with slabs to act as skewbacks (*Fig.* 398). Over this floor a layer of asphalt is laid. Since the water-pressure might push this upwards if any infiltration took place a layer of mass concrete is laid on top of it. This layer is finished off level and acts as a working floor. This type of inverted arch if made parabolic requires little reinforcement since the stress is then purely compressive and concrete is excellently adapted to resist this, but if the pressure is very high the plain arch sheet may be replaced by heavy inverted ribs spanning from wall to wall.

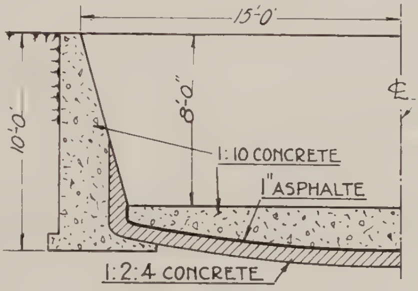


Fig. 398.

In constructions of this type an efficient pump and a deep sump, outside the work, are required. In some cases the whole ground-water level in the neighbourhood of the works has been lowered by means of powerful pumps connected to suction pipes distributed round the site. If necessary the excavation may be taken down to a foot or two below formation level and back-filled with broken stone on top of which the arch is constructed in rapid-hardening Portland cement concrete.

Water Filtration

Exactly one hundred years ago a slow sand filter was built in London to remove the turbidity of the public water supply. Some years afterwards it was discovered that the sand filter had the effect of removing bacteria from the water and its use then became general for municipal water supplies. At the present day these filters are constructed as rectangular reinforced concrete reservoirs, varying from one-half to one and one-half acres in area, with a system of drains in the bottom over which are placed layers of broken stone and gravel decreasing in size of grain from the bottom upwards. On top of these a thickness of from 2 to 5 ft. of sand is placed through which the water filters to a filtered-water well connected to the filter by the drains already mentioned. After use for some time the water supply is cut off and the sand surface cleaned before filtering operations are resumed. The method of construction is very similar to that described for reinforced concrete tanks below ground level.

In modern mechanical filtering plants (*Fig.* 399) the water undergoes an additional treatment by chemicals which produces coagulation of the materials to be removed and assists the precipitation of the suspended materials. The rate of flow through the filters is mechanically controlled.

Sewage Disposal Tanks

The introduction of the concrete septic tank to replace the dangerous dry-well has been the means of providing a simple, efficient and cheap method of dealing with the sewage from either isolated houses or large communities.

In designing a septic tank for an isolated house the dimensions should be large enough to allow of holding the whole sewage for one day. For eight to ten people an average size would be two compartments each 4 ft. by 4 ft. by 4 ft. The external walls should be of reinforced concrete not less than 6 in. thick. The same thickness will be suitable for the partition wall and for the floor slab. Provision must be made for an inlet pipe, an outlet pipe between the two compartments, and air-tight manhole covers to each compartment. The site must be selected in a position such that the field drains carrying off the effluent will have sufficient fall.

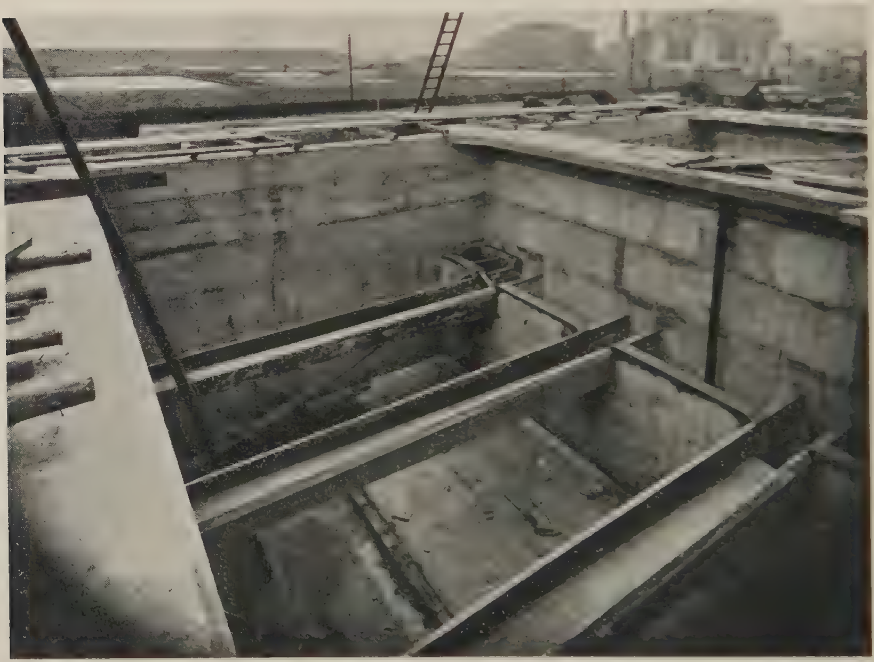


Fig. 399.—Finished Concrete in Filter.

Construction.—In good ground no outer form will be required for the external walls, and the excavation may be taken out to the outer dimensions of the tank. The concrete floor of the tank should be poured and allowed to harden, the inner box-forms of 1-in. board are then erected in position and plumbed on this floor and the pipes which are to be cast in the walls fixed through the forms. The side walls may then be poured up to the level of the top of the forms. The shuttering for the 4-in. roof slab may consist of a panel of 1-in. boards stiffened with 4-in. by 1-in. or $1\frac{1}{2}$-in. cleats and with an opening boxed out for the manhole cover. The roof slab requires reinforcement about 1 in. from its under surface; $\frac{3}{8}$-in. bars at 4 in. centres both ways are ample for ordinary loads. Some contractors prefer not to box-out a hole where the manhole opening is to be, but to saw out the opening after the concrete roof has hardened and it is necessary to enter the tank to remove the roof shuttering and its props.

City Sewage.—In municipal work the Imhoff tank is a well-known type both in Great Britain and abroad. In these the flow of sewage is through an upper compartment fitted with a bottom sloping at not less than 1·2 vertical to 1 horizontal, and ending in a sealed slot discharging into a lower compartment designed to hold not less than six months' accumulation of sludge. This sludge chamber is of conical shape and fitted with a sump. Reinforced concrete is the ideal material for this type of tank with sloping or conical bottom. General practice is to cast the bottom *in situ*, but in some cases of very large tanks it has been constructed of pre-cast reinforced concrete slabs.

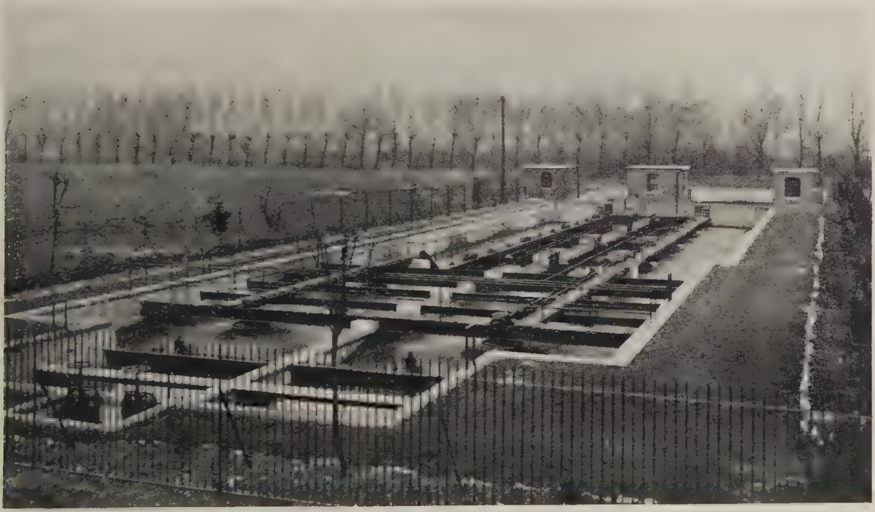


Fig. 400.—Reinforced Concrete Sewage Tanks at Epsom.

Where most of the suspended solids have been removed in settling tanks or by screens a contact bed is often employed for further treatment of the sewage. Such beds are built as watertight reinforced concrete chambers each of about 1,000 sq. yds. area and 5 ft. deep, and in groups of four in order to allow each to be rested for sufficient time to secure efficient operation.

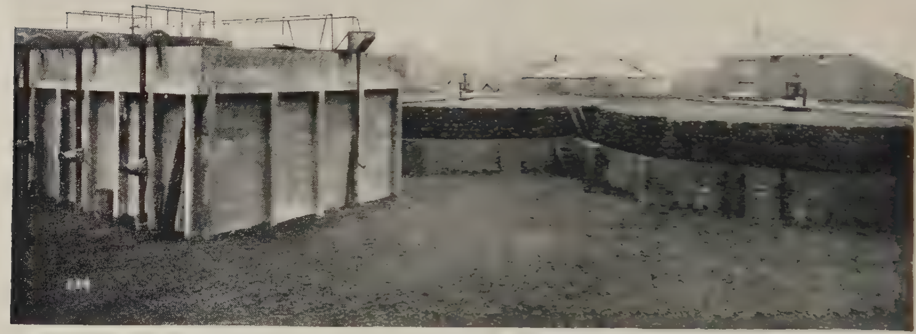


Fig. 401.—Reinforced Concrete Continuous Flow Settlement Tanks at a Sewage Works.

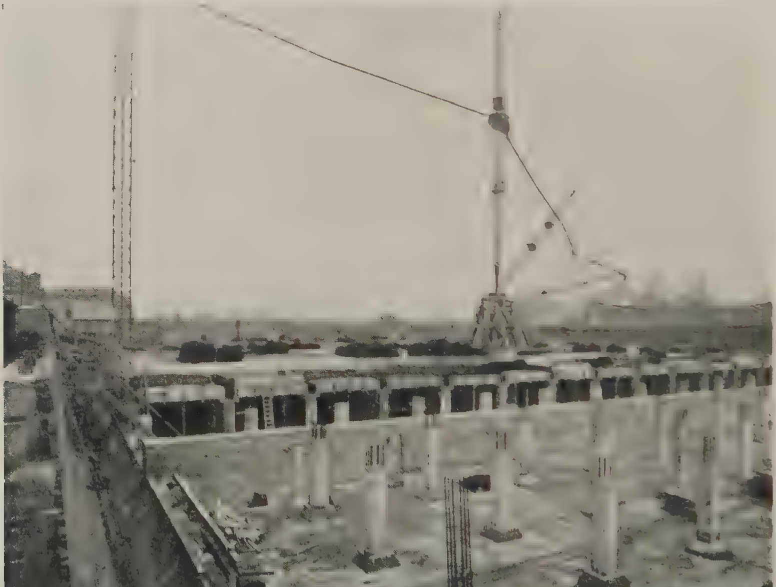


Fig. 402.—Reinforced Concrete Storm Water Tanks, Leicester.

Each compartment is filled with clinker, and has a series of earthenware field drains in the floor.

In many cities the "combined" system of sewerage is in operation, and rainwater and sewage are both discharged through the same pipes to the disposal works and outfall. In other cities the rainwater and sewerage are kept separate; one of the advantages claimed for this arrangement being that the comparatively clean rainwater does not thereby increase the volume of liquid to be treated in the purification process. *Fig.* 402 shows the different stages in the construction of large stormwater tanks at Leicester, the whole of the work being in reinforced concrete. In the background the concrete is being placed in the roof by a chuting plant. In the foreground the columns are shown concreted.

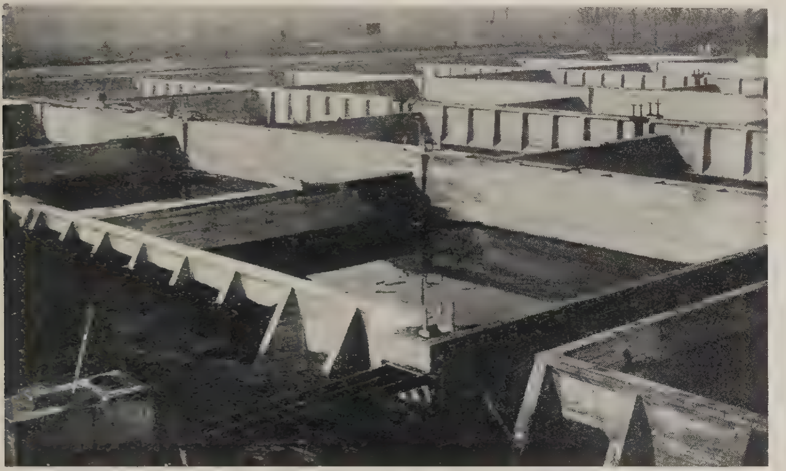


Fig. 403.—Reinforced Concrete Sewage Works at Dartford.

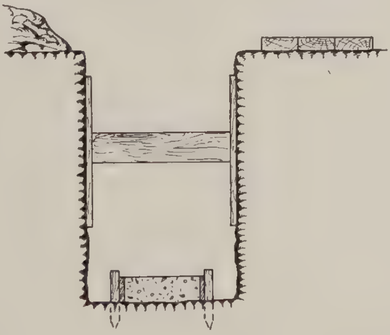


Fig. 404.

Concrete Bed and Haunching to Pipes

Formwork.—If the excavation is stiff and the weather dry, forms may often be dispensed with, the bottom of the trench being cut to the outside concrete dimensions. In poor ground the trench is cut a little wider, and forms (*Fig.* 404) consisting of 1-in. or 1¼-in. rough boards, braced by pegs or stones, erected.

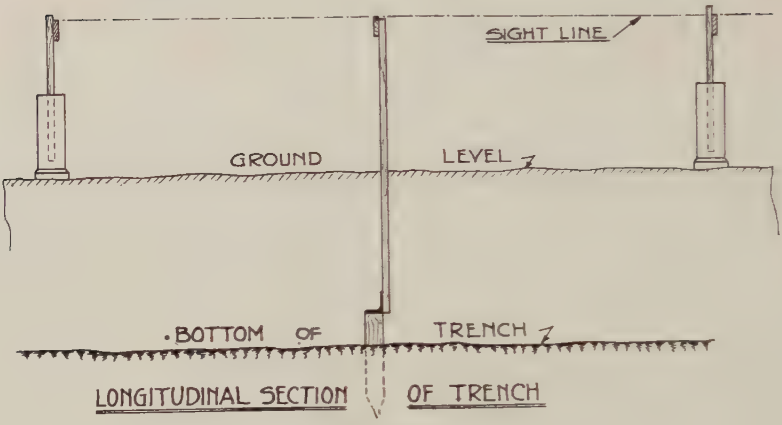

SIGHT LINE
GROUND LEVEL
BOTTOM OF TRENCH
LONGITUDINAL SECTION OF TRENCH

Fig. 405.

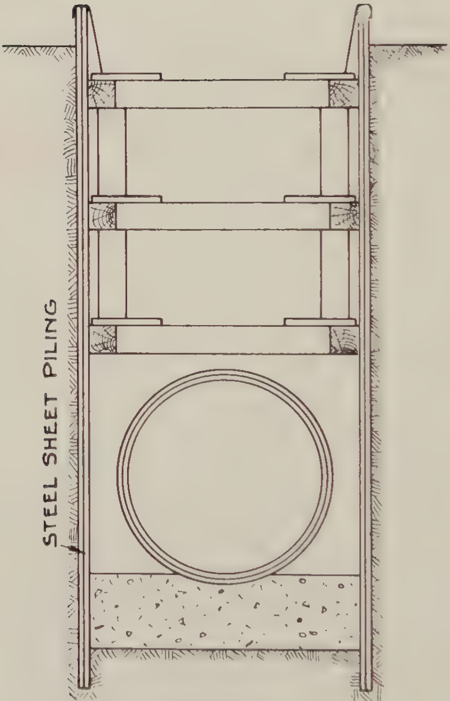

STEEL SHEET PILING

Fig. 406.—Trench Timbering.

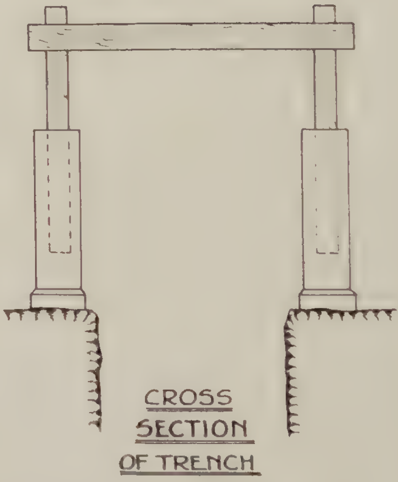

CROSS SECTION OF TRENCH

Fig. 407.

Concreting.—For this class of work the concrete is often mixed by hand and almost invariably transported by barrow. A runway is essential if the trench is not timbered, otherwise the operation of tipping the barrow may cause earth from the top of the trench sides to be shot down and mixed with the concrete. The concrete is often tipped on a timber platform alongside the trench, and buckets are filled there. The latter are lowered into the trench by a labourer standing on a plank spanning the opening.

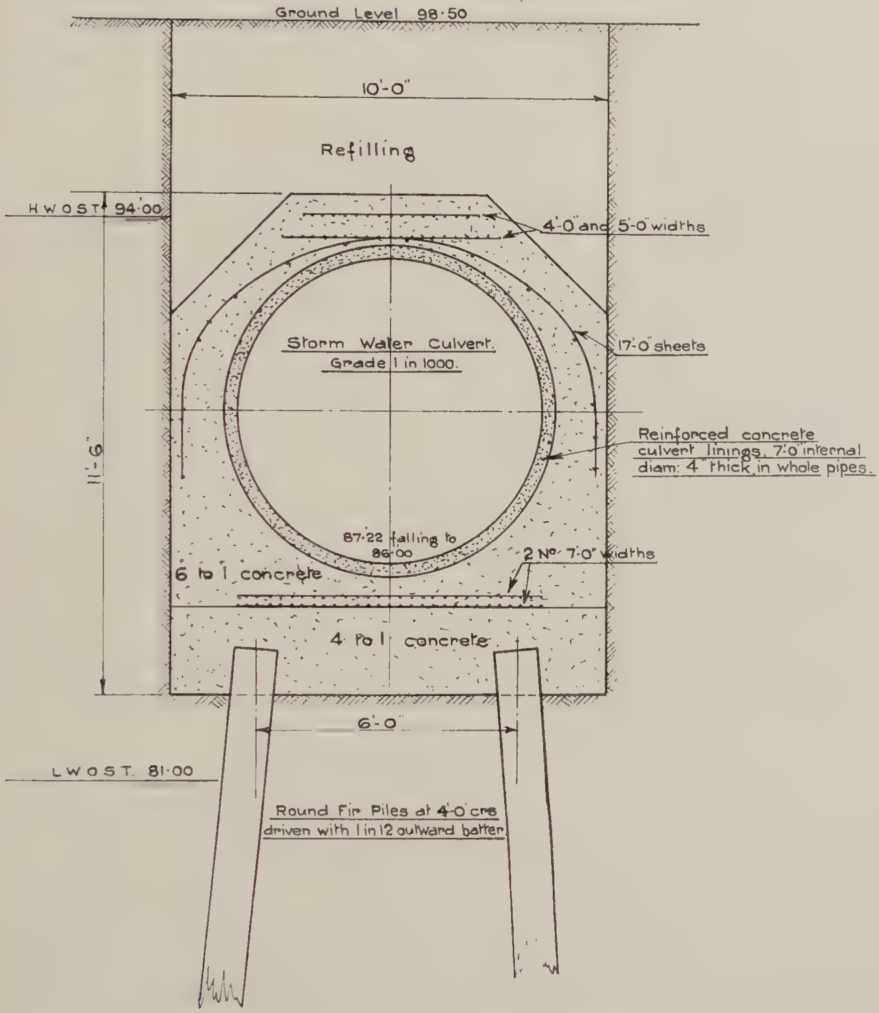

Ground Level 98·50
10'-0"
Refilling
H W O S T 94·00
4'-0" and 5'-0" widths
17'-0" sheets
Storm Water Culvert.
Grade 1 in 1000.
Reinforced concrete culvert linings, 7'-0" internal diam: 4" thick in whole pipes.
11'-6"
87·22 falling to 86·00
2 No. 7'-0" widths
6 to 1 concrete
4 to 1 concrete
6'-0"
L W O S T. 81·00
Round Fir Piles at 4'-0" crs driven with 1 in 12 outward batter

Fig. 408.—Cross-Section of Stormwater Culvert (High-Level).

In order to keep the concrete bed to the correct level, pegs are boned in (*Figs.* 405 and 407) at intervals, their tops being at the level of the upper surface of the concrete bed. The latter is generally brought up to the level required for the outside of the sockets of the pipe, otherwise holes must be left for these. The haunching is usually smoothed off with a trowel.

Pipe Joints

Experience has proved that a mixture consisting of one part of clean sharp sand to one part of " Ferrocrete " will make a mortar more than equal to the strength of the pipe material. With this mortar, if protection is given from direct sun and wind, a thoroughly tight joint may be made, free from cracks and consequent sweating and leakage.

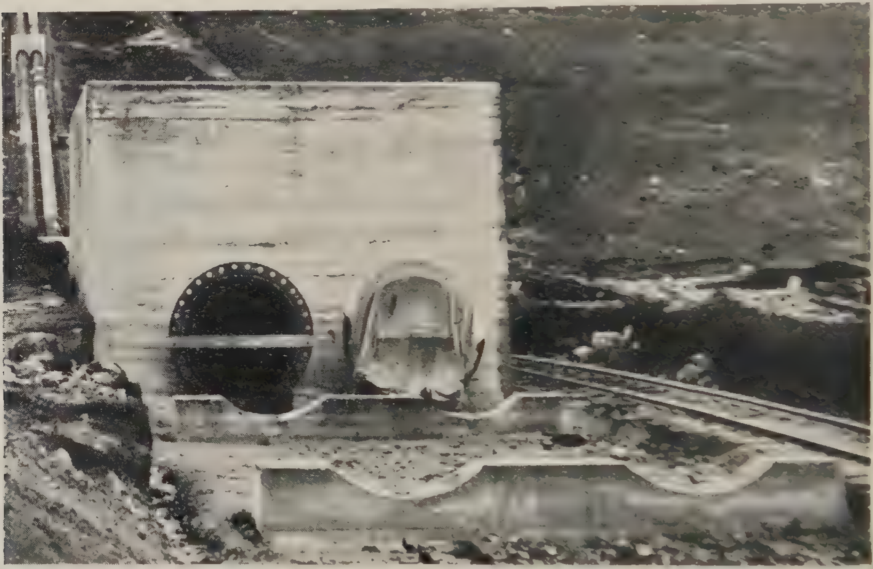


Fig. 409.—Concrete Anchor Block and Pipe Saddles.

The following may be taken as the method most usually adopted for small and medium sized pipes, which, with reasonable care and intelligence, will ensure a tight and satisfactory pipe-line.

A gasket composed of hemp, twisted jute or oakum, in one continuous piece for each joint, should be placed around the spigot of the pipe to be laid. After the spigot has been inserted into the socket of the laid pipe and well pushed home, the pipe should be brought to proper line and level at the socket end and the gasket lightly caulked with suitable tools. The remainder of the joint should be filled with cement mortar, consisting of one part " Ferrocrete " and one part clean sharp sand, carefully mixed and containing enough water so that, when balled and squeezed in the hand, moisture will just exude. Especial care must be taken to see that this mortar is pressed well into the joint on the underside of the pipe. The mortar joint is best made with the hands (protected with rubber gloves, if necessary), and should be lightly and uniformly caulked to the face of the socket, after which it may be bevelled off with a trowel.

For the larger sized pipes the use of band-wrappers has been found of considerable advantage. The joint having been first made, as described for smaller pipes, one edge of the wrapper is attached by means of a cord or wire passing round the pipe behind the socket, the other edge being similarly fastened and firmly bound immediately in front of the newly-made joint. This serves as a protection to the mortar during the setting of the joint—particularly so at the bottom or underside of the joint.

When mortar joints have to be made in wet trenches the canvas band should invariably be used. In this method a closely woven canvas band slightly longer than the circumference of the socket of the pipe, and of sufficient width to envelop completely the socket and mortar joint, is used; a length of pliable wire is inserted inside the hemmed edge, and looped at each end for security and fastening. The band may be securely fastened around and at the back of the socket by twisting up one of these wires. This should be done before the pipe is laid *in situ*. The joint may then be made in the usual manner, and the second wire tie fastened round and twisted up. This has the effect of drawing the whole wrapper tightly round the joint, supporting it and also preventing water in the trench from washing the cement out of the mortar.

By adopting the methods described a special quick-setting cement is not required for jointing, and tight pipe-mains, complying with all reasonable tests, may be ensured. Due regard should, however, be given to the careful filling in of trenches after the joints have been made, and sufficient time must be allowed for the mortar to set.

Manholes

Formwork.—In manhole construction it is not usual to erect an outer form, the concrete being placed directly against the excavation unless this is very loose. The inner form is a simple timber box built in sections about 3 ft. in height using 1-in. boards.

Concrete.—For deep manholes the concrete is lowered in buckets or small skips, and the floor finished first, the inlet and outlet pipes being cast in the walls. The channels, unless special vitrified half-sections are used, are made up in fine concrete and rendered on the surface. As soon as the bottom has hardened, the side forms are erected and plumbed, openings being left for the step-irons (*Fig.* 410). Except in shallow manholes the formwork need not be erected complete to the roof, general practice being to erect the forms in 3-ft. or 4-ft. lifts, allow this concrete to harden and then raise the forms for another 3 or 4 ft.

Reinforcement.—With the ordinary wall thickness of 9 in. reinforcement is unnecessary. In the roof a layer of fabric or expanded metal will allow of the use of a thinner slab.

Setting Frames and Cover.—As soon as the roof has been constructed, leaving a ¾-in. recess where the frame is to be set, the latter is bedded on ¾ in. of stiff cement mortar. In order to keep the frame from sinking and squeezing out the mortar, wedges or flat stones are inserted under its edge and kept there until the stiff grout has hardened.

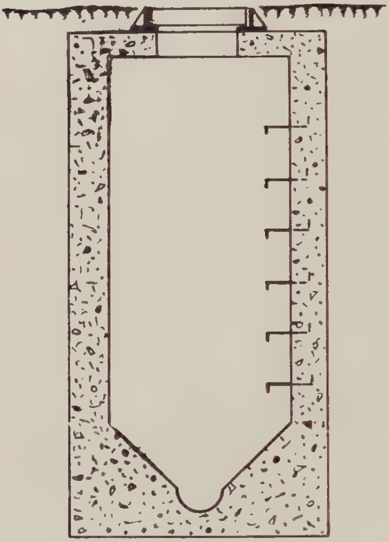


Fig. 410.

Notes on pre-cast concrete manholes are given in Part VIII.

Lampholes

In poor ground where forms are required, these are of the simplest construction, an external shutter alone being employed, the pipe acting as the internal form.

Concrete is generally put in place with a shovel as the quantity required is very small, generally a 6-in. or 9-in. thickness all round the body of the pipe being sufficient. No reinforcement is required. The top of the concrete is widened out so as to form a square extending at least 6 in. beyond the lower edge of the frame and is finished off to a level surface about ¾ in. below the final level required. The frame is usually bedded in a stiff cement mortar in a similar manner to that employed for manholes.

Cast *in Situ* Sewers

Small circular sewers may be constructed as shown on the half-sections in *Fig.* 411. Except in very bad ground the excavation may be taken out to templates such as are illustrated in *Fig.* 412, the gradient being kept true by " boning " off the top horizontal board of the template frame. When concreting the lower portion similar templates may be used to ensure the proper shape of the concrete invert being kept. Strips of jointing material are cast in the concrete and project upwards to give a good joint between invert and arch.

A suitable centre for the arch, with ribs bolted together, is shown in *Fig.* 411, supported on 9-in. by 3-in. stretchers through pairs of wedges. The centre may be built in lengths of 5 ft. The top forms for the arch may be braced as shown in the illustration. When the radius of the arch is small the lagging must be in small widths and may require to be bevelled along each edge.

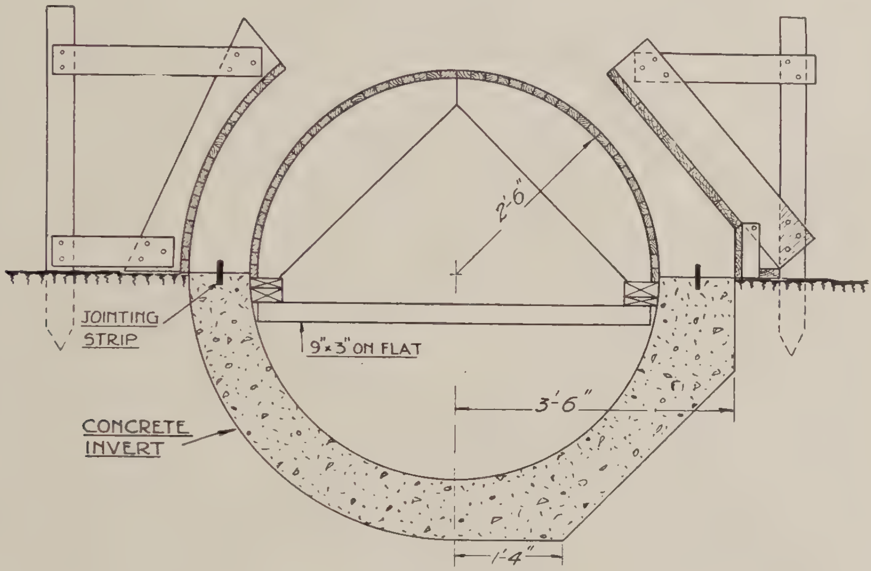

2'6"
JOINTING STRIP
9"×3" ON FLAT
3'-6"
CONCRETE INVERT
1'-4"

Fig. 411.

A portion of the forms for larger arched sewers is shown in *Fig.* 413. In this case the centre is built up of pieces of 9-in. by 2-in. timber with

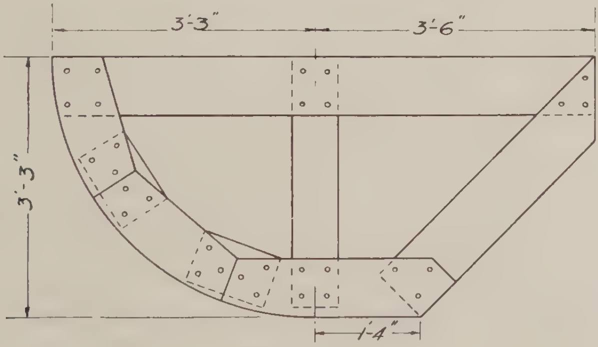


Fig. 412.

7-in. by 2-in. ties in pairs. The centre is wedged off longitudinal members resting on top of the cleats of the wall panels. The spaces behind the wedges are filled in with loose boards. A method of bracing the upper forms for the outer sides of the arch is also shown in the illustration.

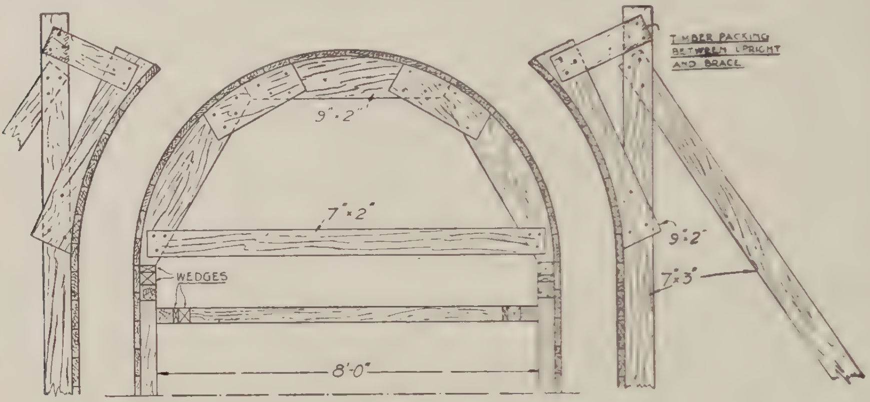

TIMBER PACKING BETWEEN UPRIGHT AND BRACE
9"×2"
7"×2"
WEDGES
8'-0"
9"×2"
7"×3"

Fig. 413.

A simple form for very small arches is illustrated in *Fig.* 414. In this case the main ribs may be of 1-in. timber, two sets of ribs at convenient centres constituting one centre. The distance between the ribs will depend on the thickness of lagging used and the facilities for handling the centres. Normally a distance of 3 ft. to 4 ft. 6 in. will be found suitable.

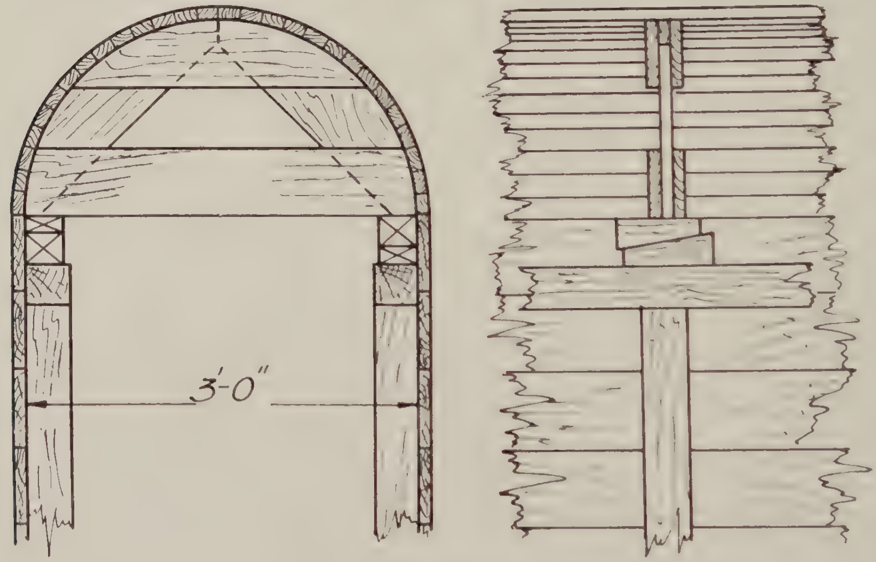


Fig. 414.

Well Construction

The minimum thickness of concrete wall for wells may be as small as 6 in. at the top; but the thickness must be increased uniformly or in stages according to site conditions. Weep holes at about 6-ft. intervals around the perimeter and at 3-ft. intervals in depth, each row staggered with respect to the one below and above, should prove sufficient in most cases. If possible, a coarse rubble pocket should be made around each weep hole. Although theoretically a well in uniform ground would only be under axial thrust in the shell, it should most certainly be reinforced to provide for the inequalities that are bound to occur in practice, particularly during construction. The amount of reinforcement should in any case not be less than $\frac{1}{2}$ per cent. of the concrete area horizontally and $\frac{1}{4}$ per cent. vertically, equally disposed on both faces, i.e. inside and outside. In well sinking, if the shaft is built above ground with a pointed cutting edge, or if casting keeps pace with sinking by digging within and loading the shell, there will be no trouble.

Concrete on the Railway

One of the noteworthy changes in railway construction and maintenance is the widespread use which is now being made of concrete as a substitute for timber, brick, and masonry, all three of which have been employed in railway works since the first tracks were laid in Great Britain. Timber which was formerly the material par excellence for fence posts, station name-plate boards, gate-posts, signal-posts, supports for loading-gauges, lamp-standards, etc., has now been replaced by concrete and most of the great companies have depots at which the articles mentioned above are manufactured in large quantities. Further particulars of these are given in Part VIII. Brickwork and masonry have been replaced by concrete for abutments and wingwalls of bridges, culverts, retaining walls, arched bridges, and tunnel linings on account of the resulting decrease in first cost and maintenance and the greater strength obtainable with concrete. In the construction of viaducts leading to docks and in the jetties connected by sidings to many main lines concrete is usually specified at the present time. The same applies to structures in which steel or iron deteriorates rapidly, such as engine-sheds (*Fig.* 415), coaling-bunkers and elevated water-tanks.

Large concrete warehouses (*Fig.* 416) are now a prominent feature of the terminals of many lines, and the satisfactory results obtained by the Great Western Railway Company since the construction, in 1911, of its warehouse at South Lambeth has led to the duplication of the building in 1928.

Many overline bridges have been built in reinforced concrete during recent years, and although the material has not been used so extensively for underline bridges in Great Britain, the progress made in this class of con-

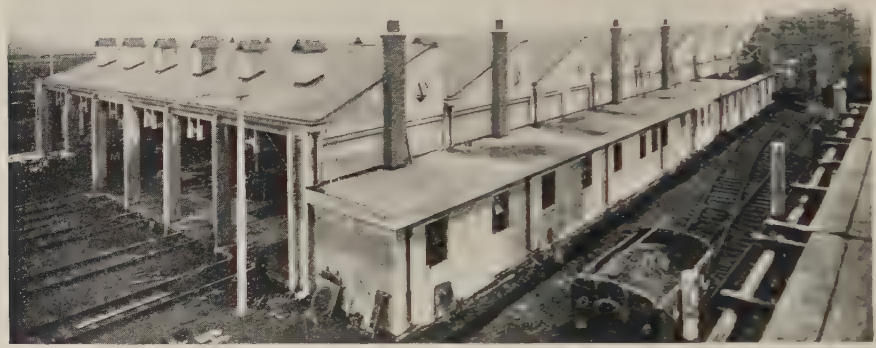


Fig. 415.—Reinforced Concrete Engine Sheds at Feltham.

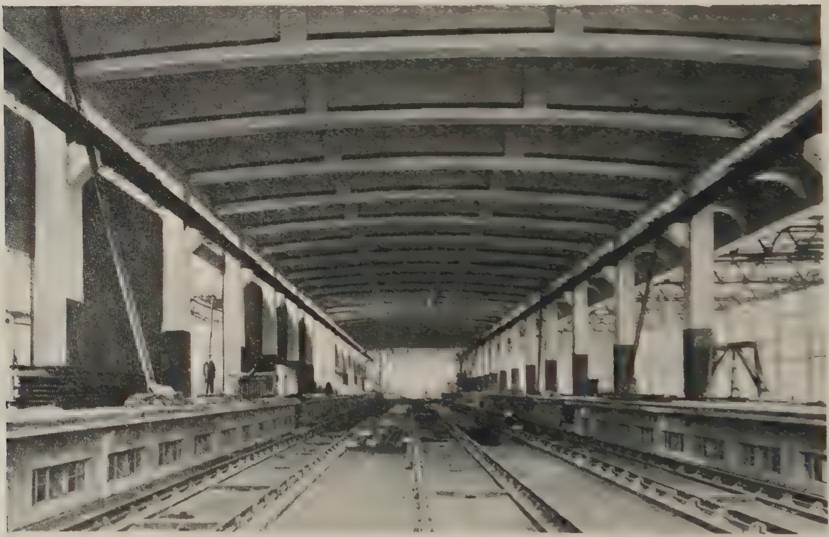


Fig. 416.—Reinforced Concrete Goods Station and Warehouse at South Lambeth for G.W. Rly. (Length 400 ft., Width 72 ft.)

struction in other countries will certainly result in British engineers following in the steps of Continental engineers in a few years. A reinforced concrete viaduct is illustrated in *Fig.* 420.

Among the structures which have been successfully pre-cast are foot-

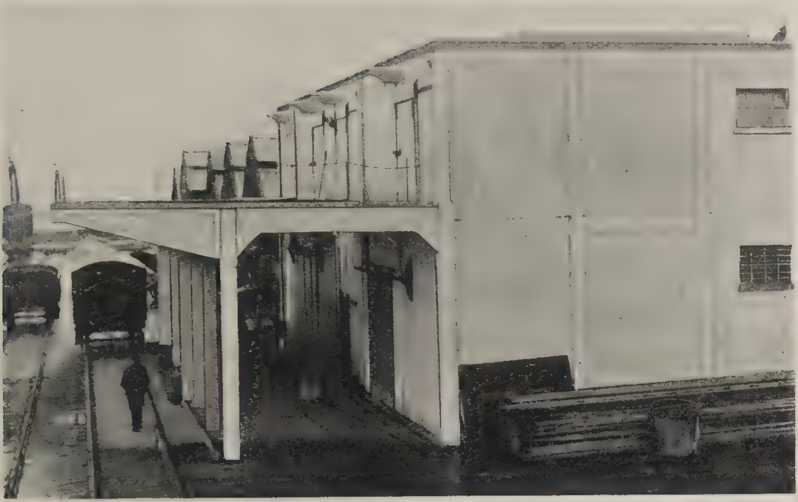


Fig. 417.—Goods Depôt and Warehouse, Plymouth, constructed entirely in Concrete and founded on Concrete Piles.

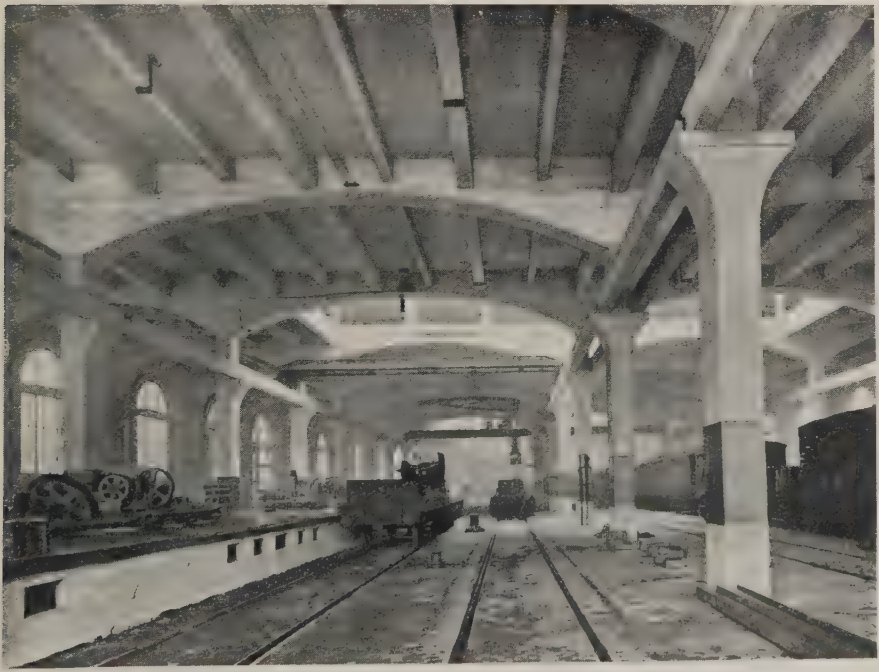


Fig. 418.—Newbridge St. Warehouse at Newcastle, in Reinforced Concrete.

bridges. In several cases these have been erected in position by loco. cranes during the ordinary period which is allowed for occupation of the lines on Sundays.

Many examples of platform consisting of pre-cast slabs supported by pre-cast trestles into which frame slabs to retain the earth filling are to be seen in Great Britain.

Concrete in Tunnels

Whether in the form of mass concrete where the tunnel runs through good strata, or where required only as a lining as in rock, or as reinforced concrete in places where the lateral pressures are very severe, concrete finds

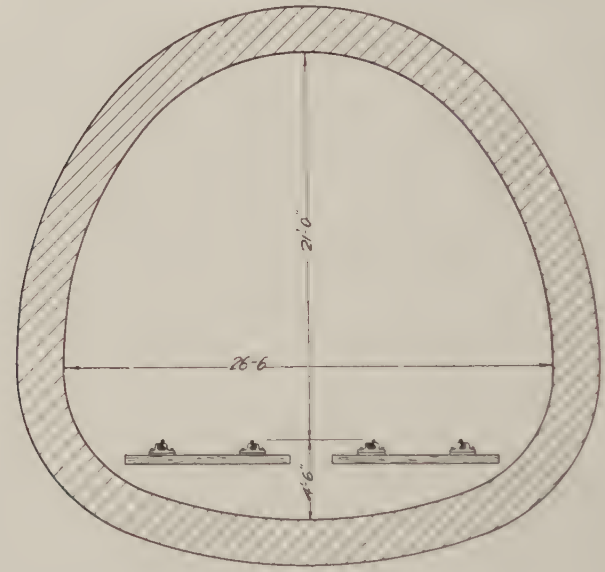


Fig. 419.

many uses in railway tunnels. A typical tunnel section is shown in *Fig.* 419. One of the advantages of concrete in this class of work is that the "overrun" of the excavation is easily filled up and voids are not left behind the back of the lining. Even where the tunnel is lined with cast-iron segments, as on underground railways, these may be filled in with concrete where stations are required and a smooth interior wall surface obtained. Other uses are in the construction of the tunnels which are a feature of hydro-electric schemes, and through which the water is led from the intake to the surge tank before passing into the pipe line leading to the turbines.

Formwork for concrete lining to tunnels is usually moved forward on travelling stages and may be built either of timber or of steel plates curved to the required radius.

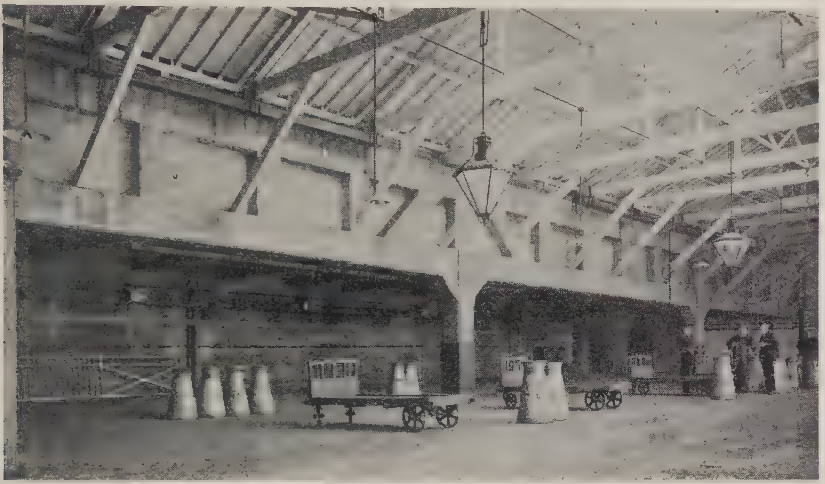


Fig. 420.—Reinforced Concrete Viaduct at Finsbury Park Station.

Concreting may be carried out with jubilee skips while the invert is being placed, but the haunches and upper portions require the use of a travelling stage. Pneumatic placing of the concrete has been used on some recent contracts.

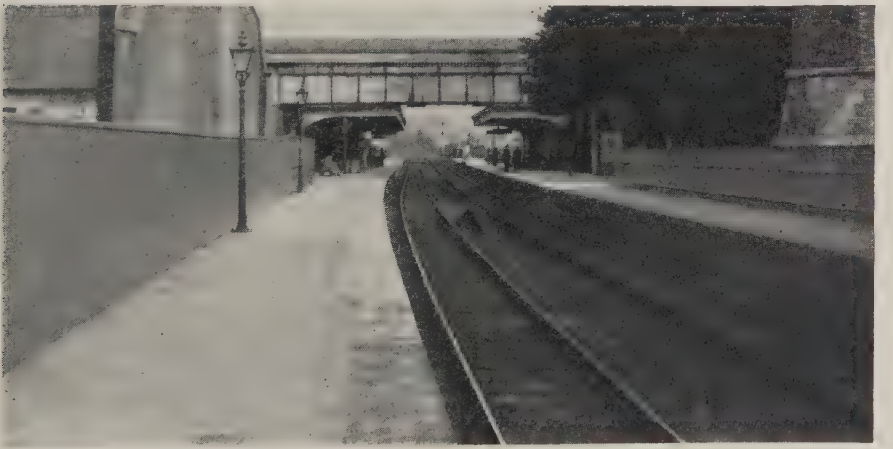


Fig. 421.—Concrete Station Platform on Great Western Railway.

Sleepers

Concrete sleepers have been made in the style of both the rectangular wood sleeper form and the steel trough shape, but as the particular properties of wood and steel which dictated the shape of the sleepers are not found in concrete, it is fairly obvious that neither of these shapes would be satisfactory and so attention has been turned to other methods of design. Apart from the two main factors, namely, the shock absorption between rail and sleeper, and the distribution from sleeper to ballast, there is a third which has caused a great deal of trouble, and that is the formation of the centre part of the sleeper. Whereas timber and steel sleepers by virtue of their natural properties are able to distribute the loads from the rails along the whole of their length without suffering from overstress, the attempt to imitate this action with a concrete sleeper nearly always leads to failure in the centre part, unless the steel reinforcement is inordinately heavy. However carefully the ballast bedding is prepared, it is impossible to prevent hogging and sagging in the length of the sleeper, the former being, of course, the worse case, resulting in the sleeper breaking its back.

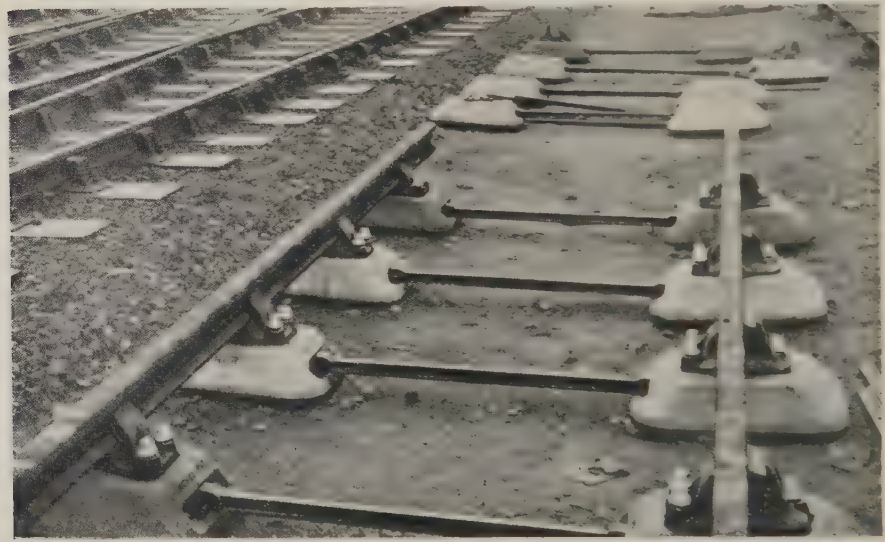


Fig. 422.

In the latest forms of concrete sleepers an effort has been made to embody the principles of correct weight distribution and shock absorption, and do away with the weak centre portion. In arriving at this design, the point to which special attention must be paid is the nature of the dynamic load on the sleeper, which is comparable with that occurring during the driving of a pile. Just as in a pile the reinforcement is mainly introduced to enable it to be handled and pitched, but is not absolutely essential for withstanding the actual driving or the load carrying (the latter two functions calling forth purely compression stresses), so the sleeper should be shaped so that the stresses produced by the rail load are calculated to utilise, so far as possible, the concrete in compression only, and the slight reinforcement introduced in the sleeper is mainly for manufacturing and transport purposes.

A form of sleeper (*Fig.* 422) embodying some of these principles consists of two blocks or pads, connected by means of a distance-bar that fits into an eye-piece in each block. By the splitting up of the sleeper into two components, the advantage of the dead load of the sleeper is maintained, without the difficulty in handling and transporting it, each block requiring only a couple of men to handle it against twice the number with a concrete sleeper. These block-sleepers, which have been tried for some years, are stated to have stood the traffic conditions well.

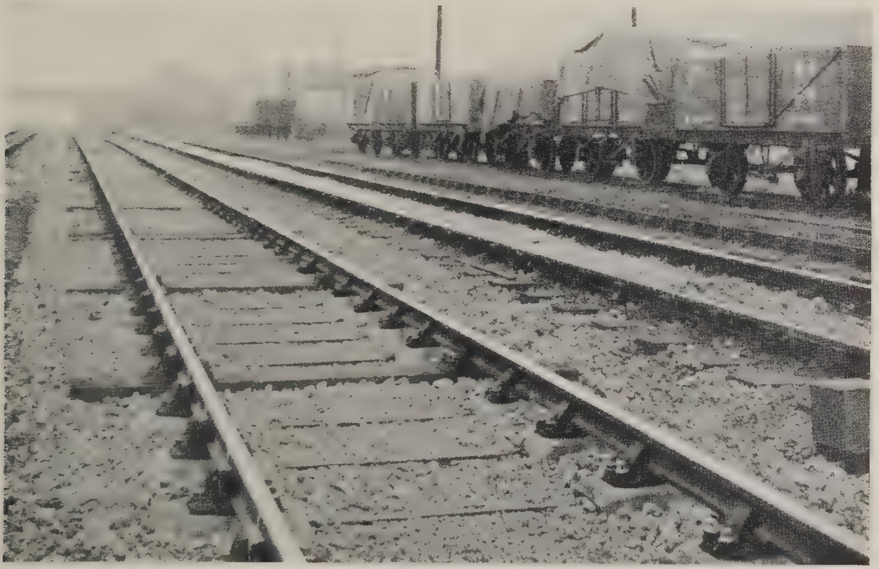


Fig. 423.—Reinforced Concrete Sleepers.

Concrete in Breweries

Concrete has replaced the copper-lined wooden tank in the tun room, and in fermenting rooms reinforced concrete tanks of 10,000 gallons capacity have been installed in addition to the ordinary water-tanks which are required in a brewery. Tanks, other than those to contain water, in breweries, are usually lined, one method being to apply an enamel which is free from action on the liquid and seldom requires repairs. The fact that some of these tanks have been in use for over 20 years is evidence of their efficiency.

Vats are generally placed on supports about 2 ft. high, the space underneath being used for tapping. Although tanks are generally constructed rectangular in plan some breweries have installed cylindrical types, the long axes being either horizontal or vertical. Reinforced concrete is also peculiarly adaptable where, as is often the case, the tanks must be of very irregular shapes in order to fill all the available space.

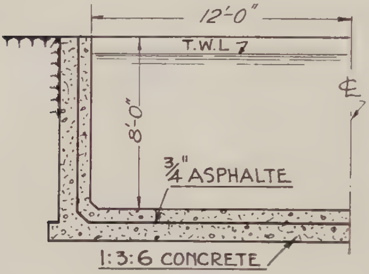


Fig. 424.

Underground tanks in wet ground must be constructed on similar lines to basements in like positions, asphalt being often used as a waterproofing medium. In such ground tanks may be built with the asphalt between an inner and outer concrete wall (*Fig.* 424) to prevent the asphalt being pushed

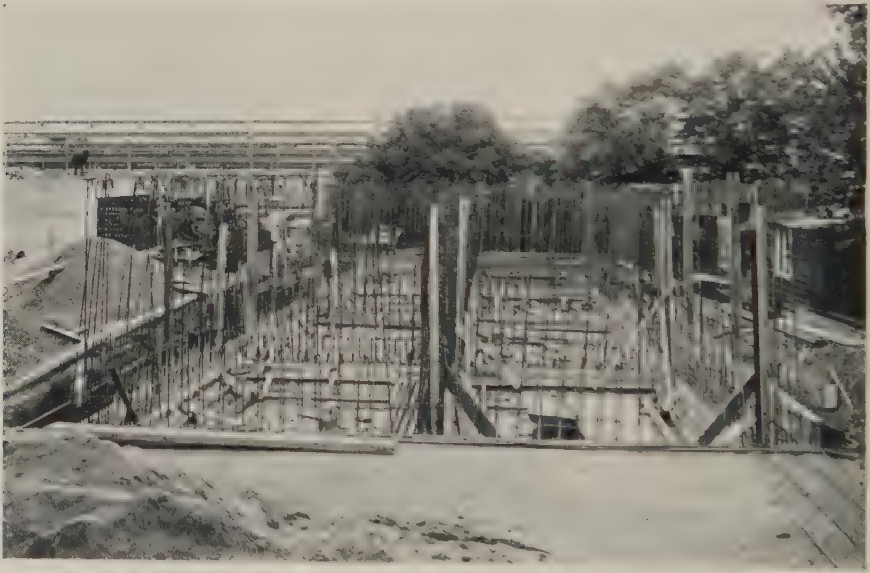


Fig. 425.—Reinforced Concrete Tanks for Storage of Wine at Kingston-on-Thames.

away from the wall as would happen if the inner wall surface were coated and the tank were empty.

Safes and Strong-rooms

Owing to the great fire-resistance of good concrete, and the difficulty of breaking or burning through heavily reinforced concrete, this material is ideal for the construction of strong-rooms and safes. Although it is common practice to use reinforced concrete for strong-rooms no photographs are available owing to the natural reticence of the owners to divulge their planning or construction.

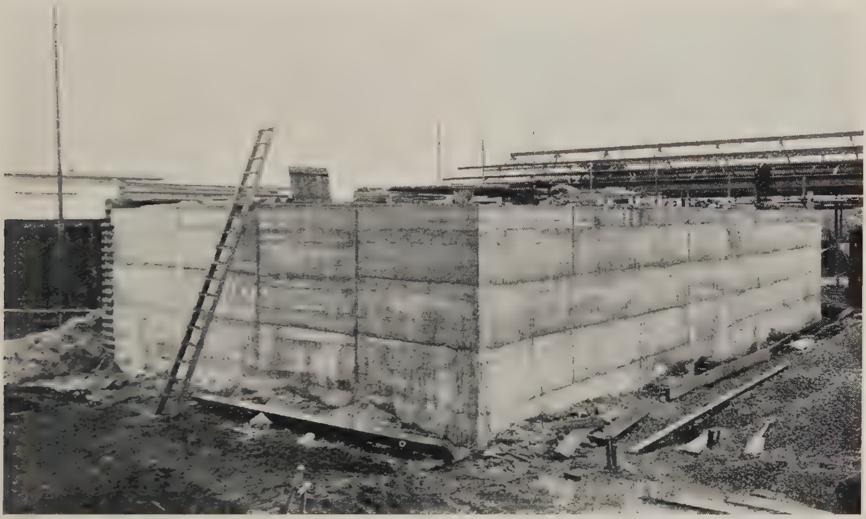


Fig. 426.—Reinforced Concrete Tanks for Storage of Wine at Kingston-on-Thames.

Reinforced concrete safes, however, may be purchased, and also reinforced concrete doors for strong-rooms. A typical reinforced concrete strong-room door is shown in *Fig.* 427, and a safe in *Fig.* 428. These safes are of monolithic construction, ensuring great strength and rigidity and eliminating all joints, rivets, and the back as a separate piece. Not only the body but the door also is of reinforced concrete, the edge of the door having a steel strip around the closing edge which fits into a corresponding steel strip around the body.

These safes are not steel safes filled with concrete, but almost entirely of reinforced concrete ; the only exposed steel are the pivots, fittings, and the light steel frames around the edges of door and body.

In considering the fire-resistance of these safes special provision has been made to prevent any possibility of flames or incandescent gases penetrating into the interior through the closing edge of the door. In addition to the close fitting of the door into the jamb, a fire-check is provided, consisting of a steel frame on the door, which fits into a corresponding frame in the body. Both these frames are insulated by concrete from the exterior of the safe.

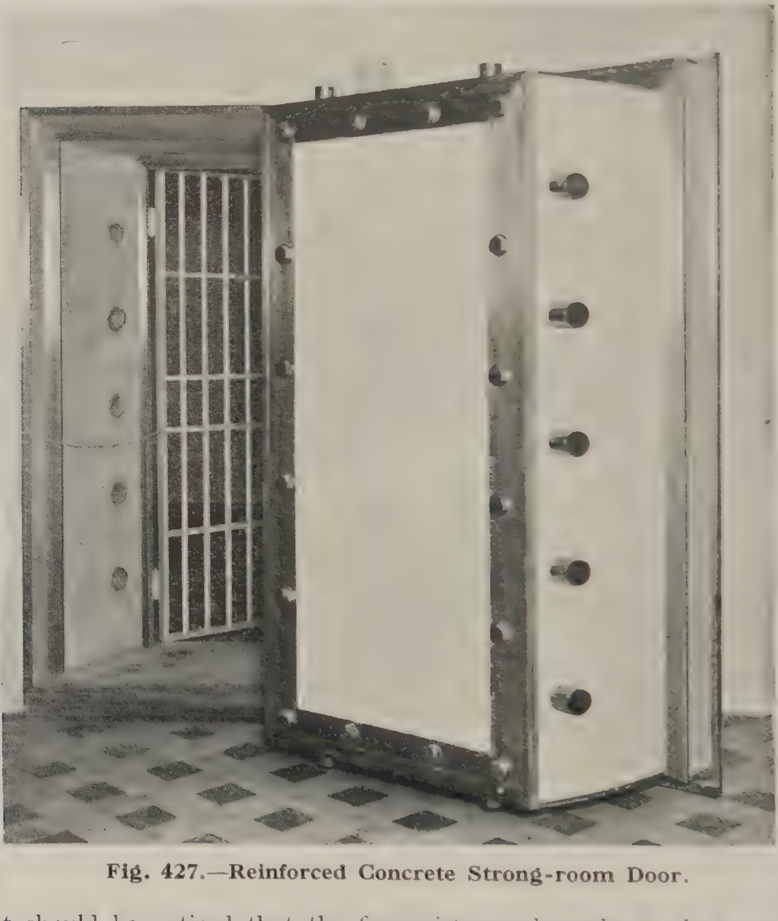


Fig. 427.—Reinforced Concrete Strong-room Door.

It should be noticed that the fire-resistance depends on the material itself, and not on any moisture-generating composition, and furthermore, owing to the low conductivity of concrete, scorching of papers, etc., in an intense fire is prevented. The reinforcement of the safes is protected by a substantial thickness of concrete, and there is no steel or iron running from the exterior into the interior, by which heat might be transmitted.

The locking and bolting system is in accordance with modern practice. Bolts of bright-drawn steel secure the doors on all sides, and shoot into sockets in the concrete frame or body. The bolting system is mounted on a steel plate covering the back of the door, which serves as an additional protection as well as providing a base for the bolting system. The additional security obtained by placing the lock at the back of the concrete and steel plate is apparent. These safes are somewhat heavier than steel safes, which may be considered an advantage in view of the frequent cases of safes being removed bodily from premises by burglars.

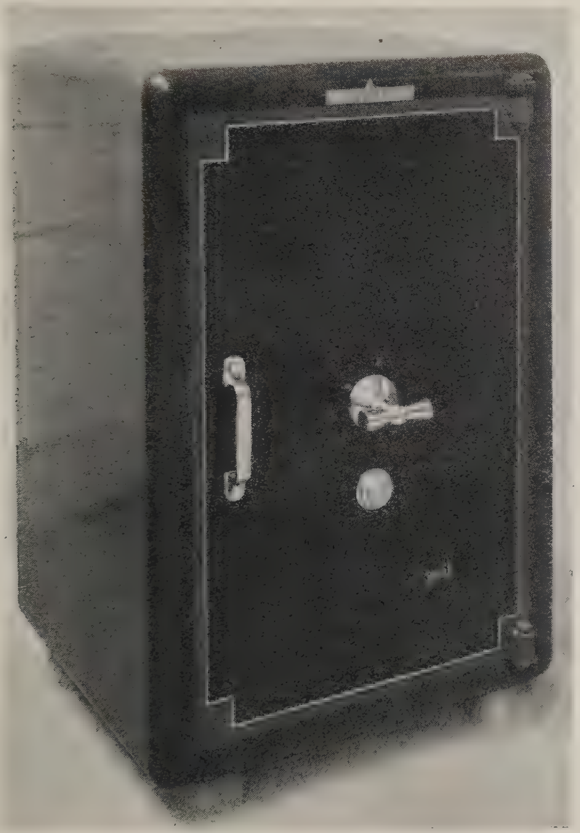


Fig. 428.—Reinforced Concrete Safe.

Strong-room doors are also made of concrete, varying from $4\frac{1}{4}$ in. to 20 in. thick, according to the purpose for which they are required. These doors, as also the safe doors, are carried on pivots, and in spite of the heavy weight they move very easily. The pivots are of special design, being anchored into the mass of concrete.

Concrete Tennis Courts

***In Situ* Construction.**—The site of a concrete tennis court should be on well-drained level ground and in a position where surface water will drain away quickly, and the least amount of filling or excavation be necessary. Where the natural slope of the ground does not allow of this, it will be found advantageous to lay a line of land drain pipes around the site. These should be placed in a small trench about 9 in. in width and well surrounded with gravel, ashes or broken stone. This pipe-line should be given as good a fall as possible—about 1 in 50 should be sufficient—and the outlet connected either to a sump filled with broken stone or gravel, or to the nearest ditch. The site of the court should be drained in a similar manner by laying a diagonal line of piping across the whole area into which other smaller lengths of pipe-line are connected.

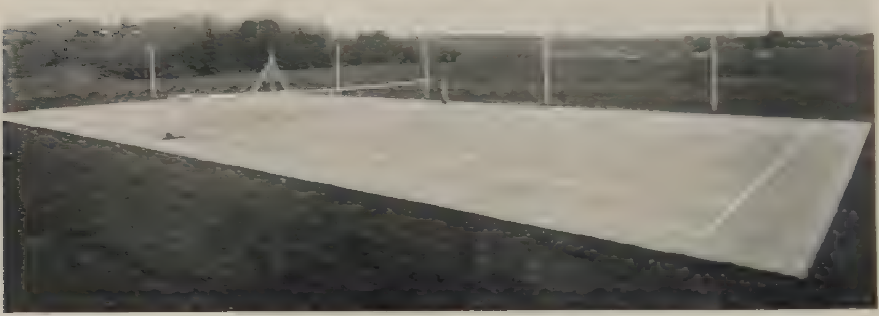


Fig. 429.—Concrete Tennis Court.

The site should be stripped until firm ground is reached, and all soft or spongy spots excavated and filled with well-tamped sand, gravel or cinders. Roots of trees and other signs of vegetation should be carefully removed. If the sub-soil is of sand or gravel, the concrete court can be laid direct on it: otherwise a 4-in. layer of well-compacted sand, gravel or cinders should be spread over the whole area to form a sub-base for the court. Before the ashes are laid it will be found advisable to give the ground a fall of about 2 in. from one side of the court to the other, so that accumulation of water is prevented and the sub-base kept firm and solid.

A full-size court is 120 ft. long and 60 ft. wide; these dimensions allow margins of 21 ft. at each end and 12 ft. at each side. The margins may be reduced if desired and 15 to 18 ft. at each end and 6 to 9 ft. at the sides are found to be sufficient for ordinary play. The margins need not necessarily be of concrete.

The concrete slab should be laid in two courses, viz. a base course $3\frac{1}{2}$ in. thick, and a top course $\frac{1}{2}$ in. thick. The court area should be divided up into convenient size bays which should be concreted in one operation and laid alternately with the sides vertical. This gives a complete butt joint between each bay, allowing for contraction and expansion. An expansion joint $\frac{1}{2}$ in. in width and the full depth of the slab should be provided at the net line, thus dividing the site into halves. This can best be done by fixing a $\frac{1}{2}$-in. board or plank along the half-court or net line and concreting the slabs on each side; the board may then be removed and the space filled with sand or tarred felt.

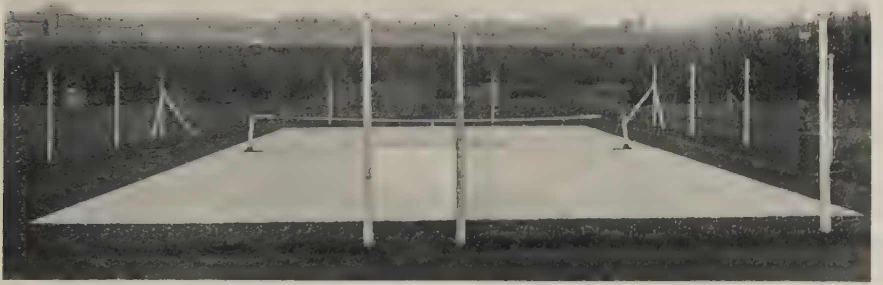


Fig. 430.—Concrete Tennis Court.

Satisfactory lines can be painted on the court surface with a white concrete paint which can be renewed every few years at very little cost. Permanent lines that need no painting can be obtained by fixing $\frac{1}{2}$-in. timber lathing on to the bottom course and filling the top course around these. The timber is then removed and the space thus formed filled with white mortar composed of "Snowcrete" white cement and sand.

The mortar for the top surface may be coloured a suitable shade by the use of "Colorcrete" or mineral pigments. If a red effect is desired, the addition of approximately 1 part of red oxide of iron to 10 parts of Portland cement will produce a good shade: a better tone may be obtained if red sand instead of ordinary sand is used for the top surface, and red oxide in the proportion of about 6 per cent. by weight of the cement content added to the mixture. If a green colour is desired, approximately 1 part of oxide of chromium should be mixed with every 9 parts of Portland cement. The bottom course should be composed of 1 : 2 : 4 concrete; the top course should be composed of 3 parts sand to 1 part cement.

Each bay must be completed when once concreting has started, and the surface coat should be laid within half-an-hour of the lower course so that the whole slab shall be monolithic in character. Each bay should be left for 48 hours to dry out before an adjoining bay is laid against it.

The mortar for the top surface should be mixed fairly stiff and spread evenly on the lower course and brought to a smooth surface by means of wooden floats or screeds.

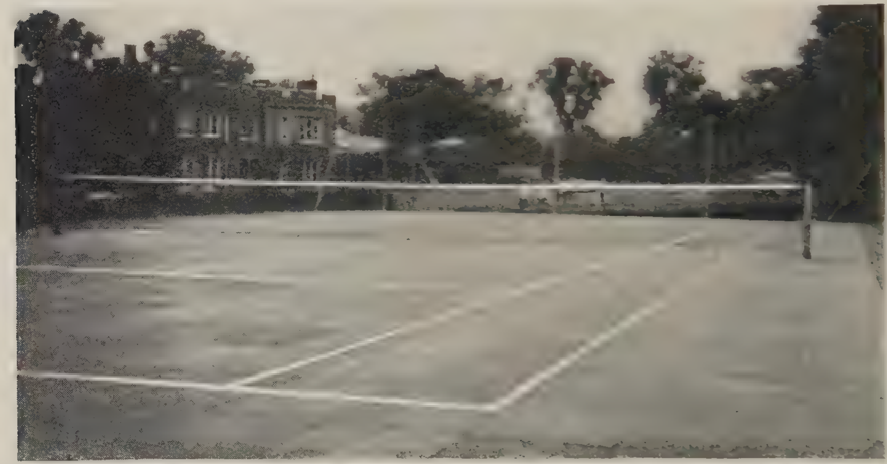


Fig. 431.—Pre-cast Concrete Tennis Court.

MATERIALS REQUIRED FOR EVERY 100 SQ. FT. OF COURT.

		Portland Cement.	Sand.	Stone.
Bottom course . .	3½ in. thick	5½ cwts.	½ cb. yd.	1 cb. yd.
Top course . . .	½ in. thick	135 lbs.	4½ cb. ft.	—

Cinder filling to sub-base per 100 sq. ft. of area = 1¼ cb. yds.

If necessary to put in drains, add approximately 300 lineal ft. of drain pipes and 40 cb. yds. of cinder. Include also ½ cb. yd. of 1 : 2 : 4 concrete to foundations of the two net posts.

Pre-cast Tennis Courts.—An increasing number of tennis courts are now being laid with pre-cast concrete slabs of the usual size of paving flags. The joints between the slabs do not in any way affect play or cause erratic bounding. The flags may be coloured to any desired shade. The site is prepared in the same way as described for *in situ* courts, and the flags laid on spots of mortar at each corner and at the centre, pressing them down level and firm. This has the effect of causing the flags to be supported from the base at five points, and prevents them from resting directly on the ash sub-base, so that water passing through the joints between the slabs (which are not mortared together) is able to soak under the slabs and so into the foundation. This type of court has the advantage that should it get worn or damaged in any part it is a simple matter to replace the slabs affected, or remove the whole court to a new site.

Porous Concrete Tennis Courts.—A very satisfactory tennis court can be constructed with porous concrete. The usual procedure is to roll in 4 in. of gravel, cinders, or ashes on which is laid 3-in. thickness of clinker concrete mixed in the proportions of 8 parts of clinker, ranging in size from 1 in. to ¼-in., to 1 part of Portland cement. The surface of the court is then formed with a ¾-in. thickness of brick concrete. The aggregate for this should consist of broken brick passing a ¼-in. sieve and retained on an ⅛-in. sieve. The correct proportions for the mix are 5 parts of broken brick to 1 part of Portland cement to which has been added 10 per cent. by weight of red oxide.

Concrete in Sea-Water

The supports of such structures as wharves and jetties which are alternately exposed to water and air as the tides rise and fall have always been liable to deterioration. Notwithstanding the many experiments which have been carried out to discover a substance which will protect timber against attack by marine organisms, a method has not been found which can be relied on to give protection for more than about three years in some waters or to give any protection in some localities. Prolonged experiments with steel exposed to sea-water prove that the rate of corrosion varies in different localities and that there is no steel which will resist corrosion in all circumstances.

The introduction of reinforced concrete has provided a satisfactory solution to this problem. The surface action of sea-water on concrete is negligible. Dense concretes are unaffected by sea-water and the secret of success is in avoiding the use of porous mixtures. With the latter the sea-water enters the pores and crystallisation of salts takes place each time the concrete is dried out with falling tides, causing expansion and disruption of the concrete.

Concrete for use in sea-water "between wind and water" should be dense and have a non-porous surface.

Marine Works

The protection of land against the sea is a difficult problem. One type of reinforced concrete groyne consists of pre-cast slabs fitting into grooves cast in the sides of reinforced concrete piles. In many cases where reinforced concrete groynes have been erected the spaces between them have been filled up and the movement of the shingle confined to their ends.

Another protective method is to construct sea walls with very long and flat slopes which are paved with reinforced concrete slabs laid between and bonded to concrete beams which run in the direction of greatest slope of the wall. The inclination of these walls varies from 1 in 3 to 1 in 8. In some examples the upper portion of the slope is curved so as to be concave towards the impinging water.

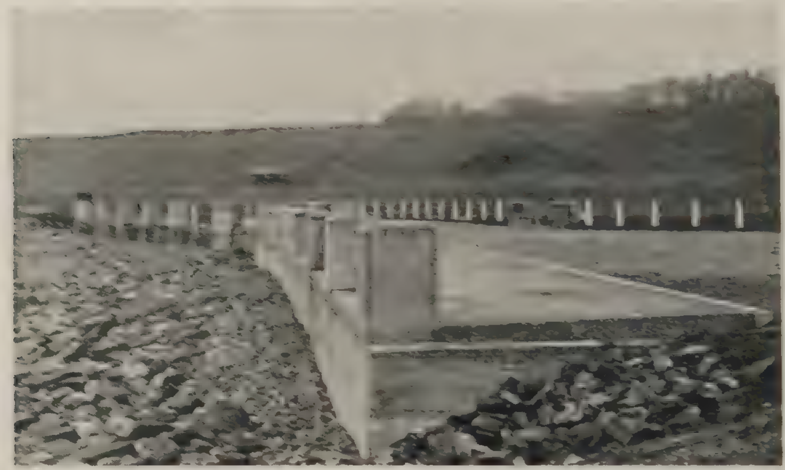


Fig. 432.—Reinforced Concrete Esplanade at Arbroath.

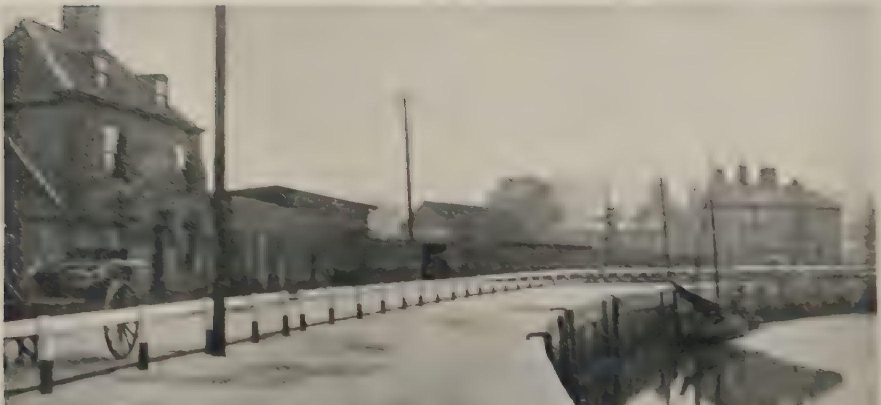


Fig. 433.—Reinforced Concrete River Wall at Boston.

Concrete walls with steep faces reflect the waves and the undermining of the foot of the wall must be guarded against. This is sometimes done by

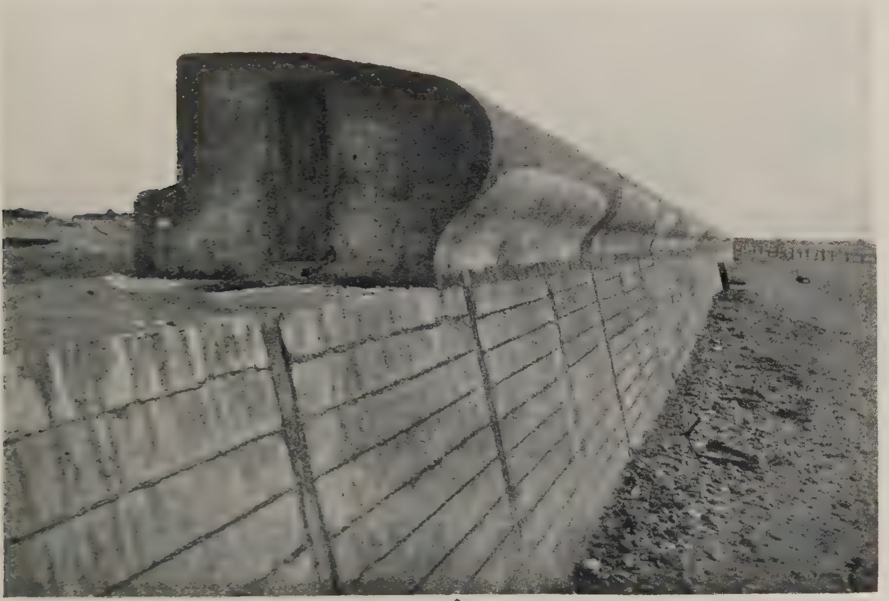


Fig. 434.—Reinforced Concrete Sea Wall at Fleetwood.

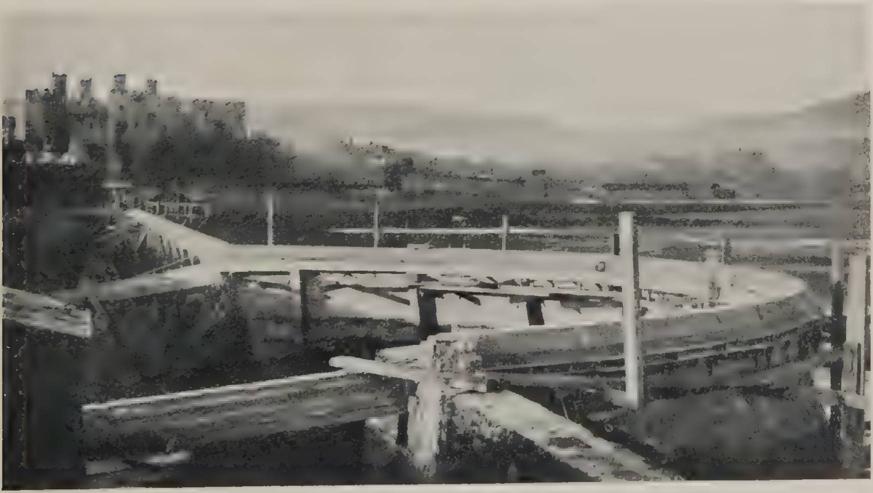


Fig. 435.—Reinforced Concrete Sea Wall at Conway.

constructing the wall face in the form of steps with a view to dissipating the energy of the waves.

Breakwaters may either run out from the land or be constructed as separate structures at the entrance to an inlet of the sea. Both monolithic construction and very large pre-cast concrete blocks handled by sheer

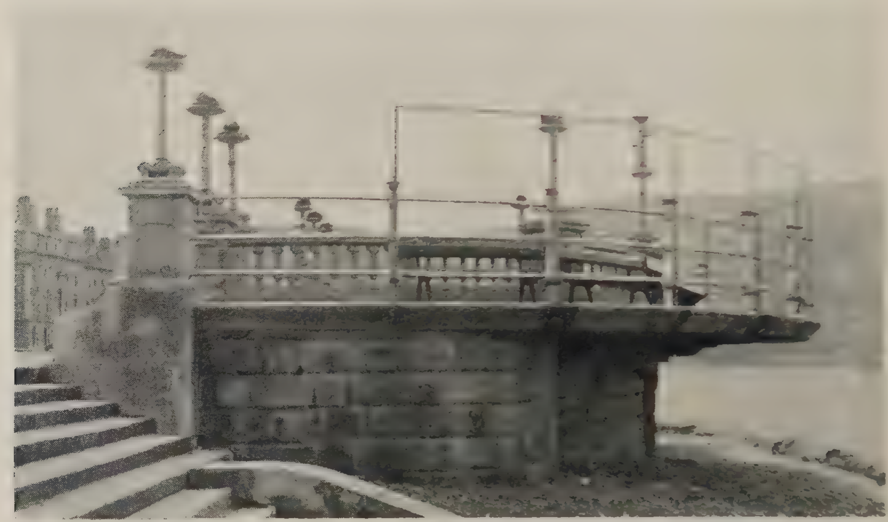


Fig. 436.—Reinforced Concrete Bandstand at Llandudno.

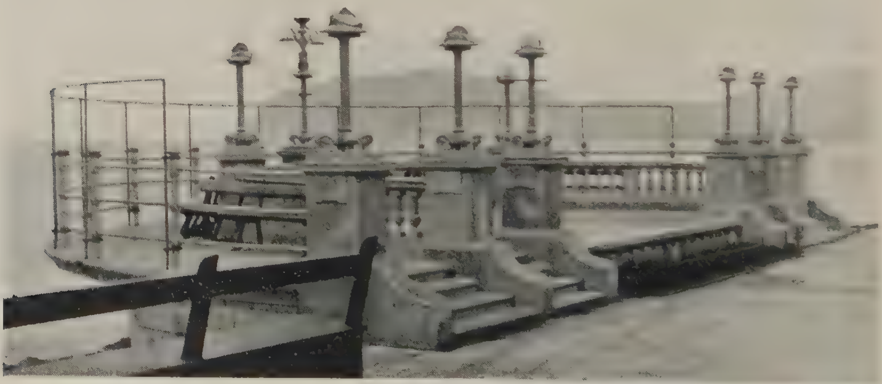


Fig. 437.—Reinforced Concrete Bandstand at Llandudno.

legs or Titan cranes and laid either on a horizontal bed or with joints in a plane inclined to the vertical have been employed in breakwaters and quays.

At Newhaven the monolithic method was used, the concrete being deposited in a semi-plastic condition so as to conform to the irregularities of the sea-bed. Jute sacking was employed to hold the 100-ton masses of concrete. The enclosed blocks, over 40 ft. in length, were dropped from a vessel and piled to form a concrete structure on which the superstructure was built in concrete laid in forms.

Small tide deflectors have been constructed in estuaries by driving two rows of reinforced concrete sheet-piles from a barge and connecting their heads by a rigid slab, the intervening space being filled in with quarry rubble. In fairly shallow water construction of this type can be carried out at a very reasonable cost and has proved valuable at the entrances to fishery harbours.

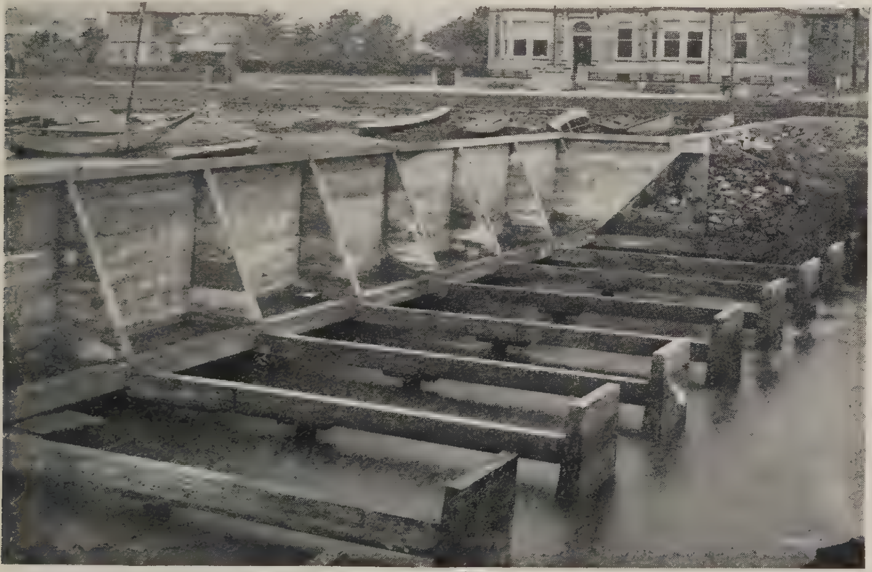


Fig. 438.—Reinforced Concrete Retaining Wall at Larne Harbour, Co. Antrim.

Quay Walls and Docks.—The use of large concrete blocks was introduced by the late Mr. Stoney who laid blocks weighing 100 tons in a quay wall in Dublin many years ago. In modern works such as the Tilbury Docks and Southampton Docks the type of construction is that known as the well or monolith in which monoliths consisting of large built-up concrete

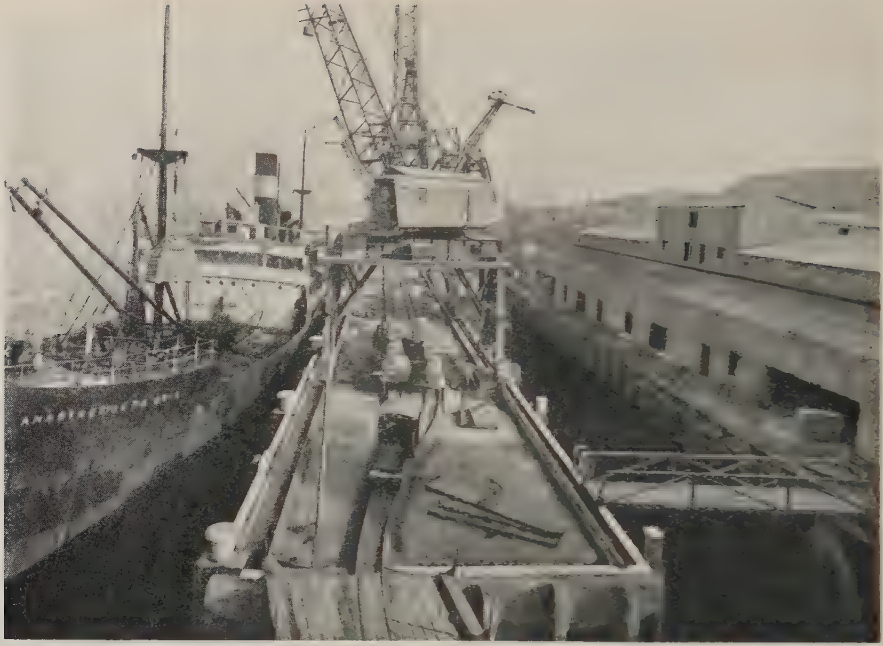


Fig. 439.—Deep-water Jetty at Bevans Cement Works.

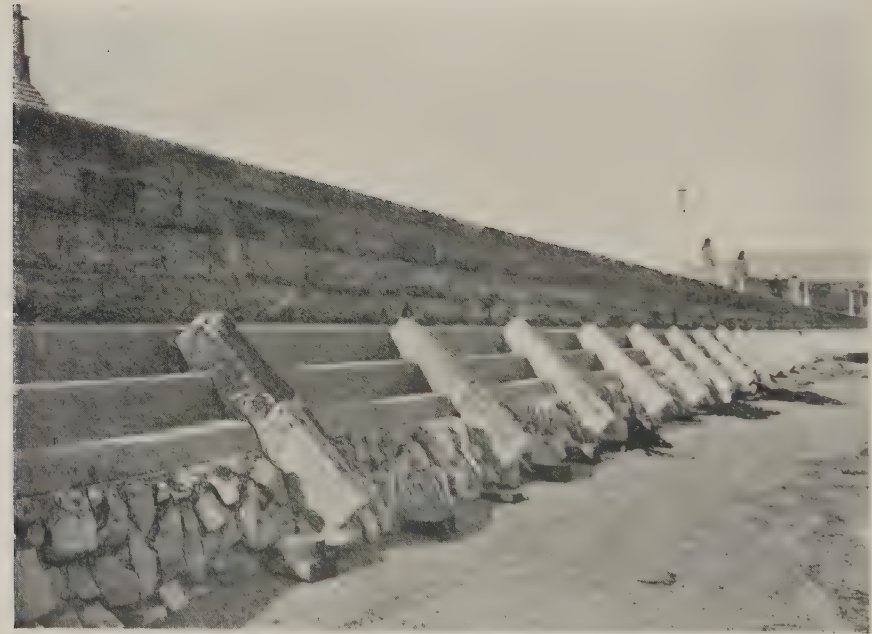


Fig. 440.—Swanage Sea Defences.

block boxes, 30 ft. or more square, are sunk in the ground. These have four inside walls and shoes of reinforced concrete to form a cutting edge.

The monoliths are sunk by continuously loading the sides with cast-iron kentledge blocks each up to 7 tons in weight, as much as 1,000 tons weight being placed on one monolith. To assist the sinking, the earth which is forced within the monolith walls is simultaneously grabbed out by a crane working from the top. As depth is obtained additional heightening courses of blocks are built up (*Fig.* 441) and this process is repeated until ballast is reached.

The monoliths are sunk contiguous to each other along the line of quay, and when the chain is complete the hollow wells are filled with concrete and sealed, the whole forming a continuous solid concrete foundation when the intermediate spaces are filled. On this foundation the superstructure of the quay walls proper is built up of mass concrete and the desired working quay level obtained by filling behind the wall. Monolith construction avoids the alternative method of deep excavation in timbered trenches.

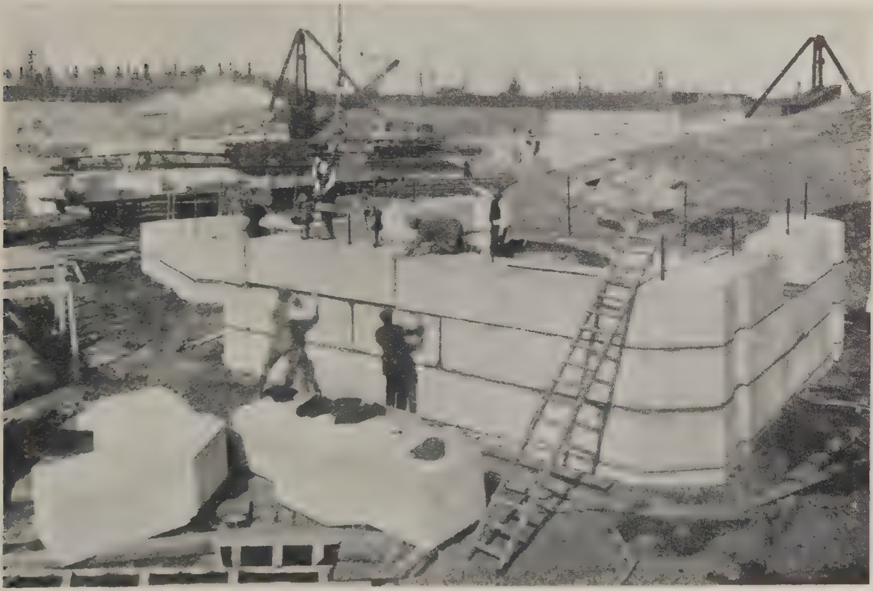


Fig. 441.—Monolith Blocks at Tilbury Docks Extensions.

The monolith course blocks are cast in wooden forms at a special block-making yard, where they are allowed to mature before being transported to the site for use.

Fig. 444 illustrates the Gladstone Dock, Liverpool. A general view of the Royal Edward Dock, Avonmouth, is shown in *Fig.* 445.

An interesting type of construction was used in the reinforced sea-wall at Ramsgate (*Figs.* 446–8). This wall is 3,000 ft. long and 17 ft. high above the foreshore. It is composed of pre-cast counterforts, slabs, and anchor beams. The counterforts are 10 ft. apart and of a triangular shape, the front part having grooves on both sides in which slide the slabs forming the front of the wall. The bottom supports the anchor beams, which support the filling at the back of the wall and prevent this from overturning.

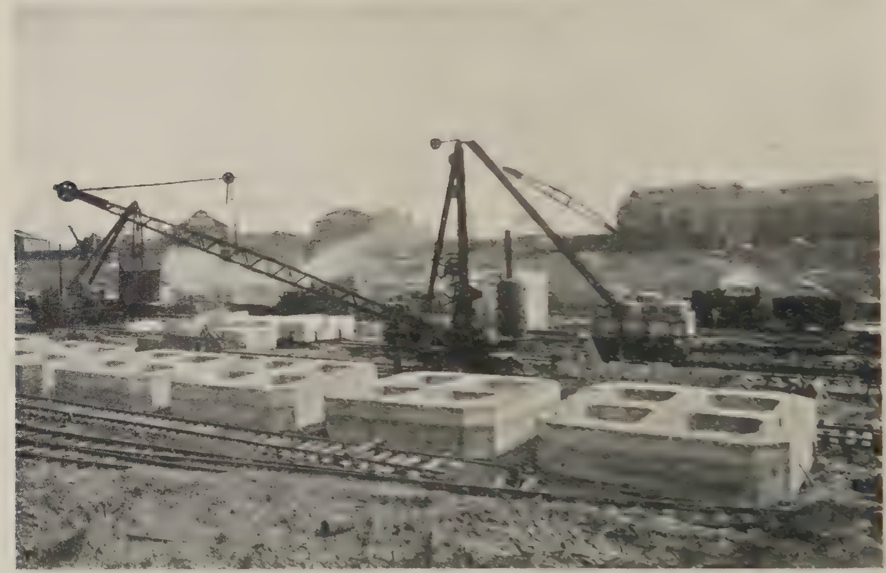


Fig. 442.—Reinforced Concrete Monoliths at Tilbury Dock.

The main advantages of this type of construction are:

(1) Cheapness of concreting.

(2) The conditions under which the steel is placed are such as to ensure accuracy.

(3) The concrete is well matured before coming in contact with sea-water.

(4) The quality of the concrete when the parts are pre-cast can be tested before being placed in position.

(5) The wall can be built between tides, without the use of a cofferdam.

(6) Speed of execution is increased.

All the parts were concreted on top of the cliff, which is about 90 ft. high.

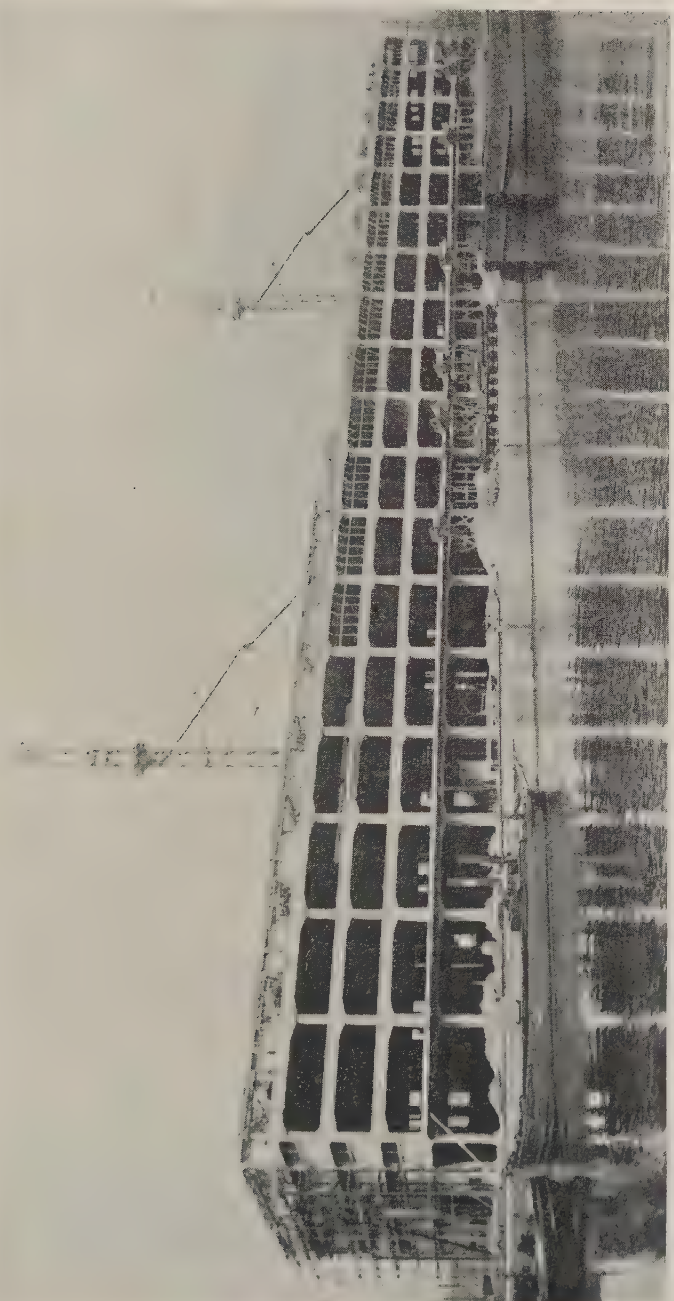


Fig. 443.—Reinforced Concrete Shed at Manchester Ship Canal.

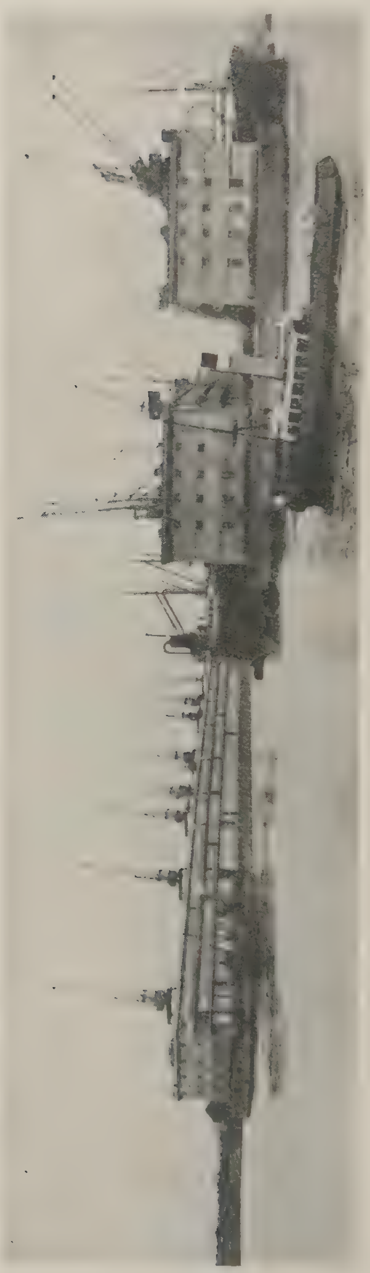


Fig. 444. Gladstone Docks, Liverpool.

There are 18 cu. ft. of concrete and about 1 cwt. of steel per foot run of wall.

Wharves and Jetties.—The rapid decay of timber when used as piles in sea-water and the failure of all the known methods of preserving wood against the destructive action of marine boring organisms has resulted in the almost general adoption of reinforced concrete as the material par excellence for harbour-works. Even if timber were not subject to decay, its increasing scarcity in the long lengths of heavy scantling which are necessary for piling in marine works has raised the first costs of such works to a figure approximately equal to that of the same works when executed in reinforced concrete. The cost of maintenance of reinforced concrete is extremely low—there are many reinforced concrete structures in existence to-day on which not one penny has been spent on maintenance since they were first erected twenty or thirty years ago. Low maintenance cost combined with reasonable first cost naturally lead engineers to specify reinforced concrete in preference to other materials.

The design of a jetty or wharf depends on many considerations and is a subject which can only be touched on in a book of this nature. The loads to be carried will depend on the kind of cargo-handling machinery to be installed, the height and floor-loads of the warehouses on wharves, whether a direct connection is provided to the nearest railway line or the materials landed

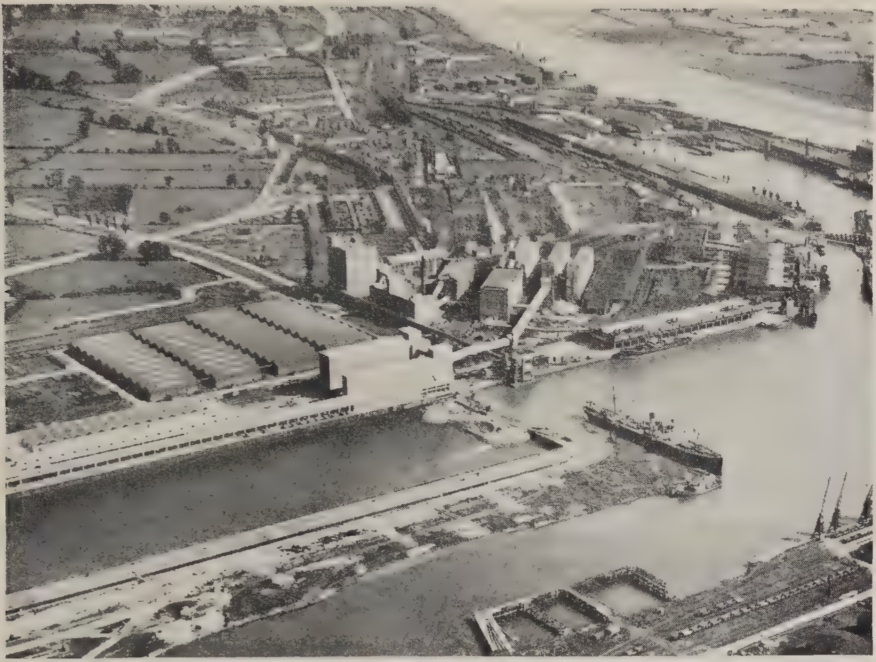


Fig. 445.—Royal Edward Dock, Avonmouth.

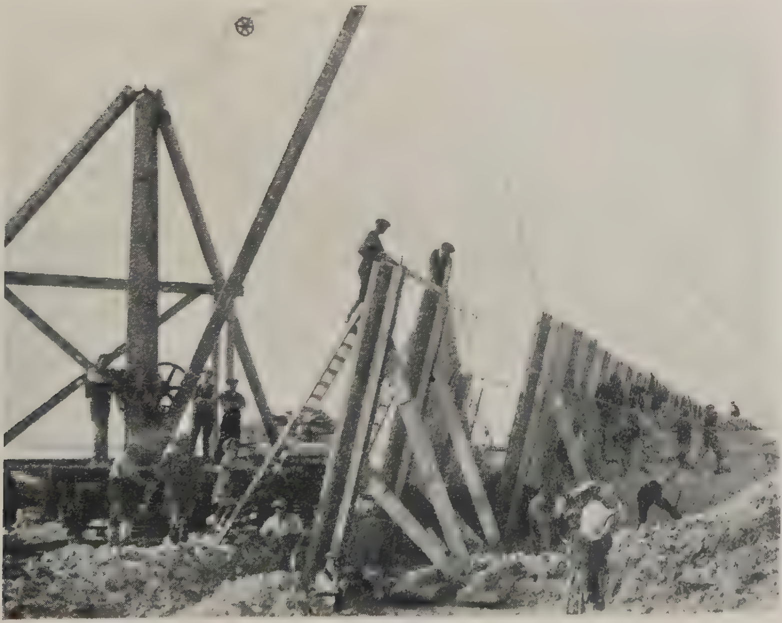


Fig. 446.—Reinforced Concrete Sea Wall at Ramsgate.

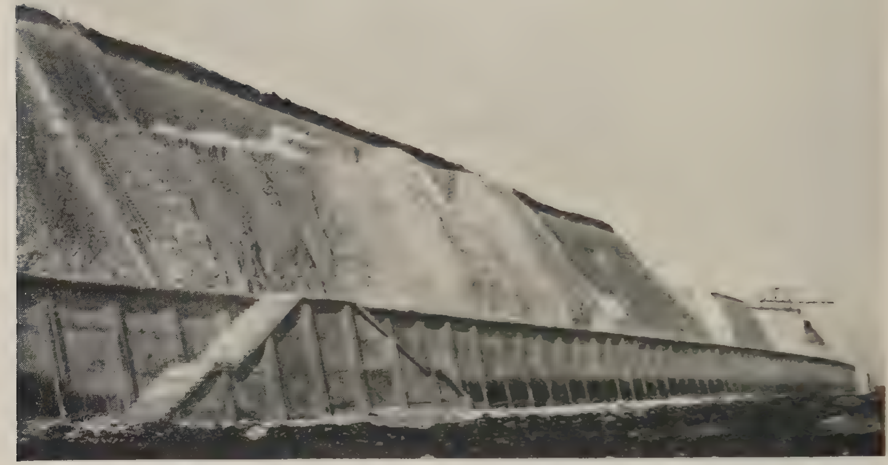


Fig. 447.—Ramsgate Sea Wall.

from ships are taken away in lorries or carts. The range of the tides and the nature of the sub-soil will both have an influence on the design of a jetty. The decking is often constructed of the slab and beam type, particularly if moving engine or crane loads must be carried. Where ware-

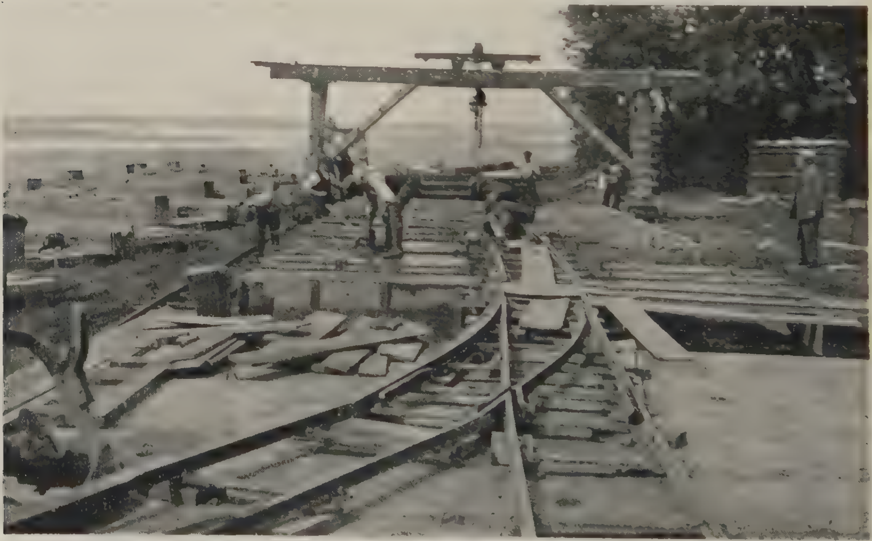


Fig. 448. Sea Wall at Ramsgate: Making Pre-cast Units.

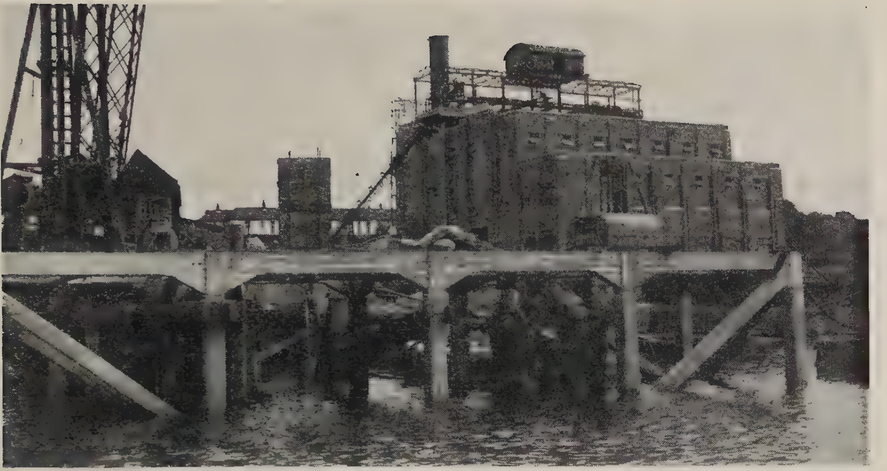


Fig. 449.—Reinforced Concrete Jetty, Isle of Wight.

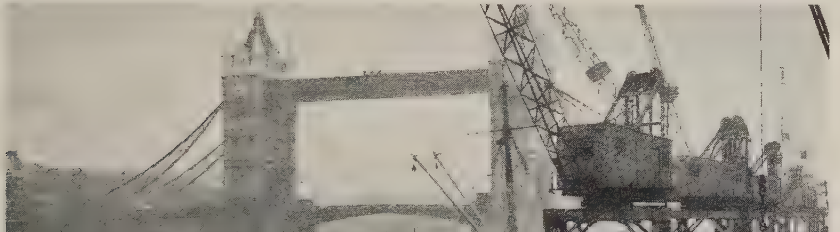


Fig. 450.—Reinforced Concrete Jetty on the Thames.

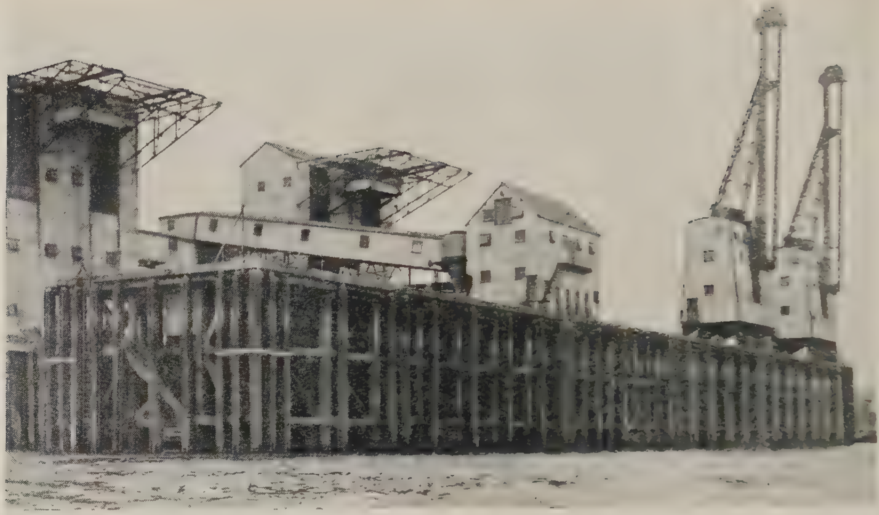


Fig. 451.—Reinforced Concrete Jetty at Erith.

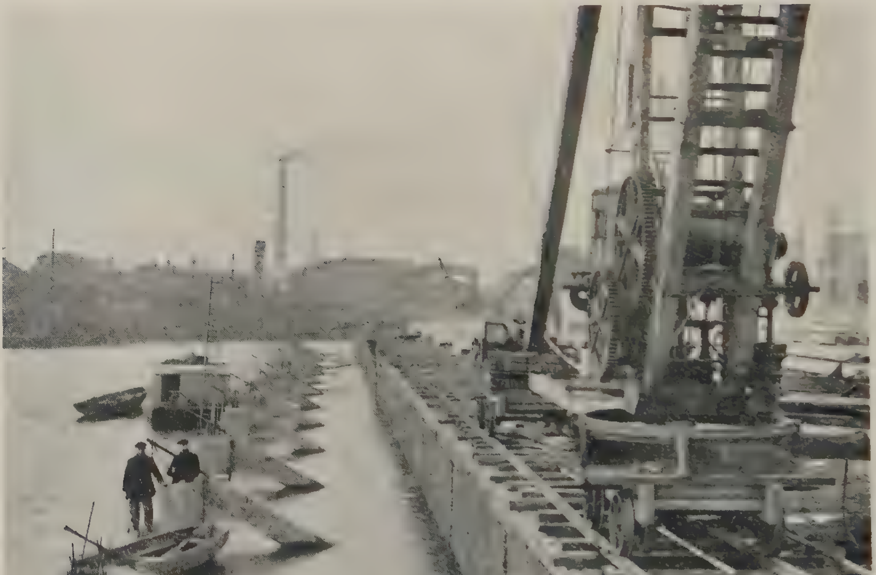


Fig. 452.—West India Export Dock, Port of London Authority.

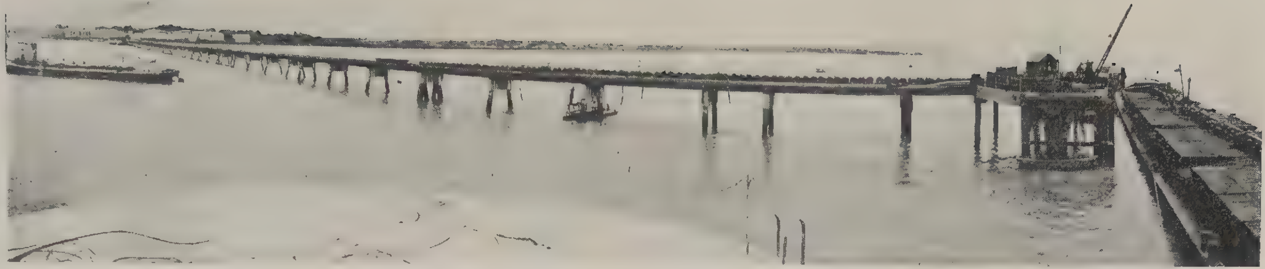


Fig. 453.—Reinforced Concrete Jetty at Hamble.

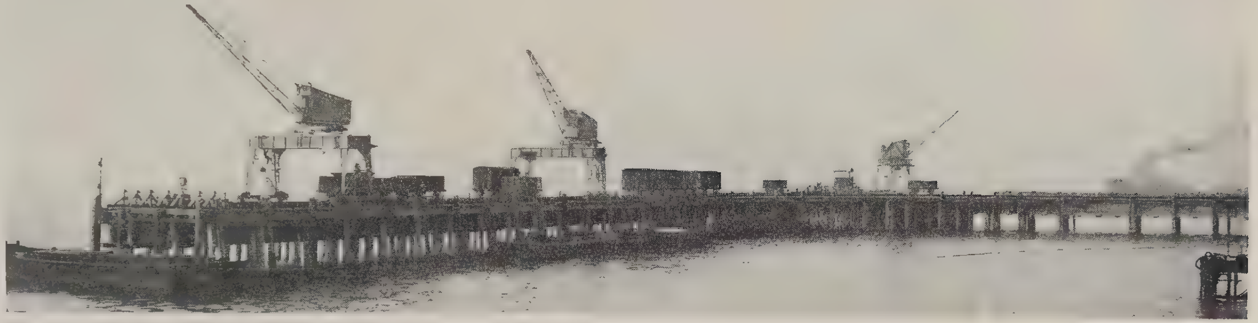


Fig. 454.—Reinforced Concrete Jetty at Purfleet.

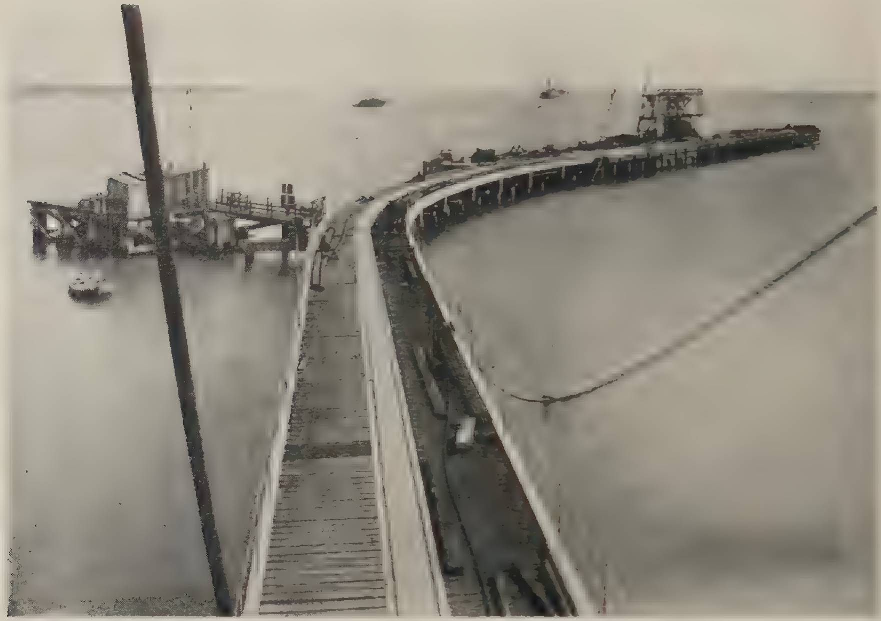


Fig. 455.—Reinforced Concrete Jetty at Fawley.

houses of several stories with heavy uniform floor loads are required the flat-slab floor is often preferred, the columns being carried on groups of piles spaced at as much as 20-ft. centres.

Many different arrangements of pile-layout have been used. In some the lateral forces caused by impact of vessels are taken by diagonal bracing, in others raking piles have been used for the same purpose. Whichever

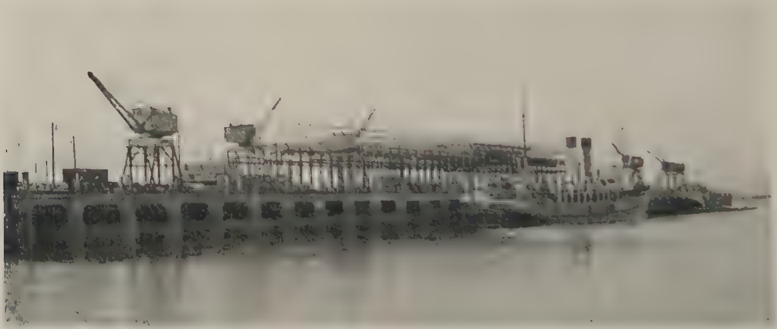


Fig. 456.—Reinforced Concrete Quay at Parkeston.

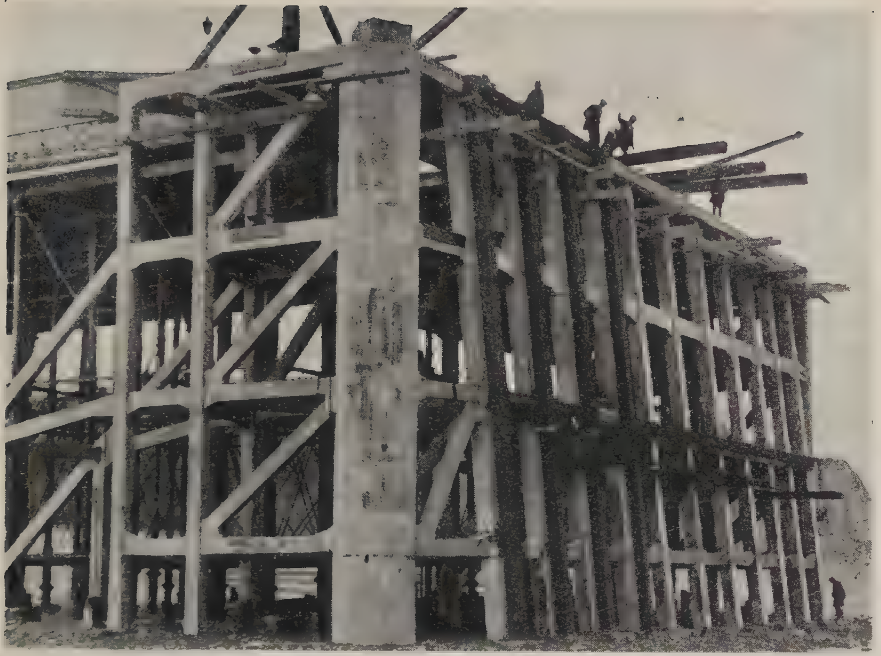


Fig. 457.—Penarth Pier : Reinforced Concrete Landing Stage.

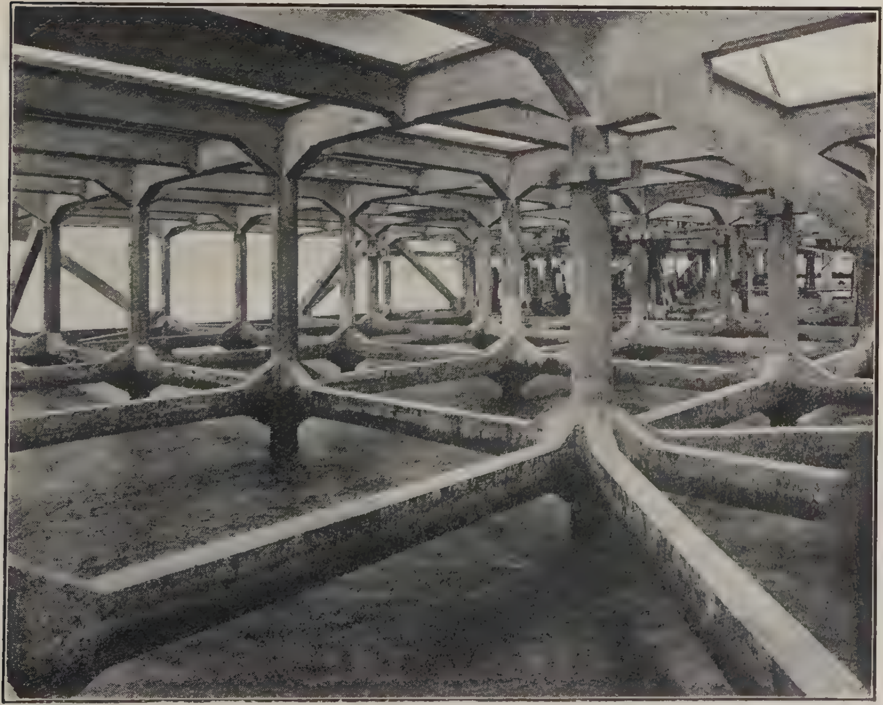


Fig. 458.—Reconstruction of Boscombe Pier Head.

design is chosen it is good practice to introduce fenders either of the fixed or loose type to deaden the impact. The monolithic nature of reinforced concrete and the fact that the decking acts as a very deep girder in a horizontal plane helps to distribute the effect of impact and ensure that the jetty is undamaged even when a heavy cargo steamer collides with it as sometimes happens.

A type of construction which is often used at docks is that shown in *Fig.* 459 where the substructure is of reinforced concrete cylinders braced by pre-cast members. The illustration shows connection being made between cylinders and braces.

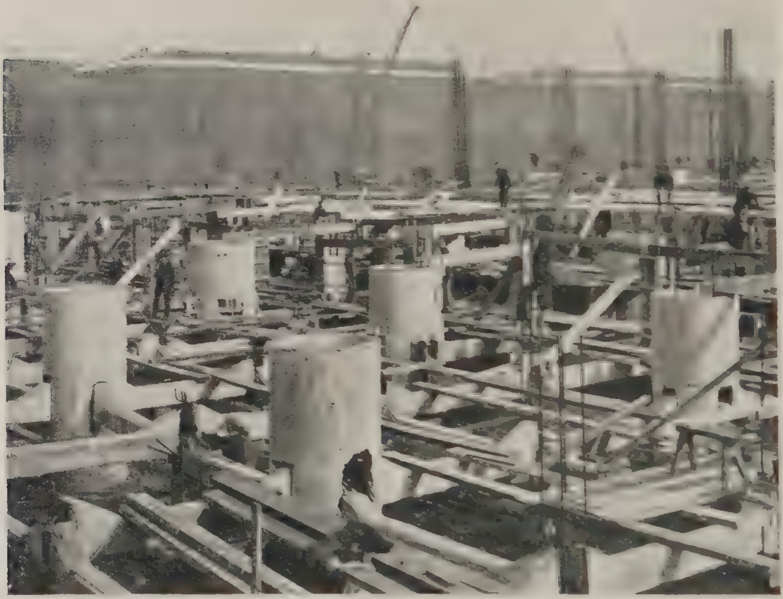
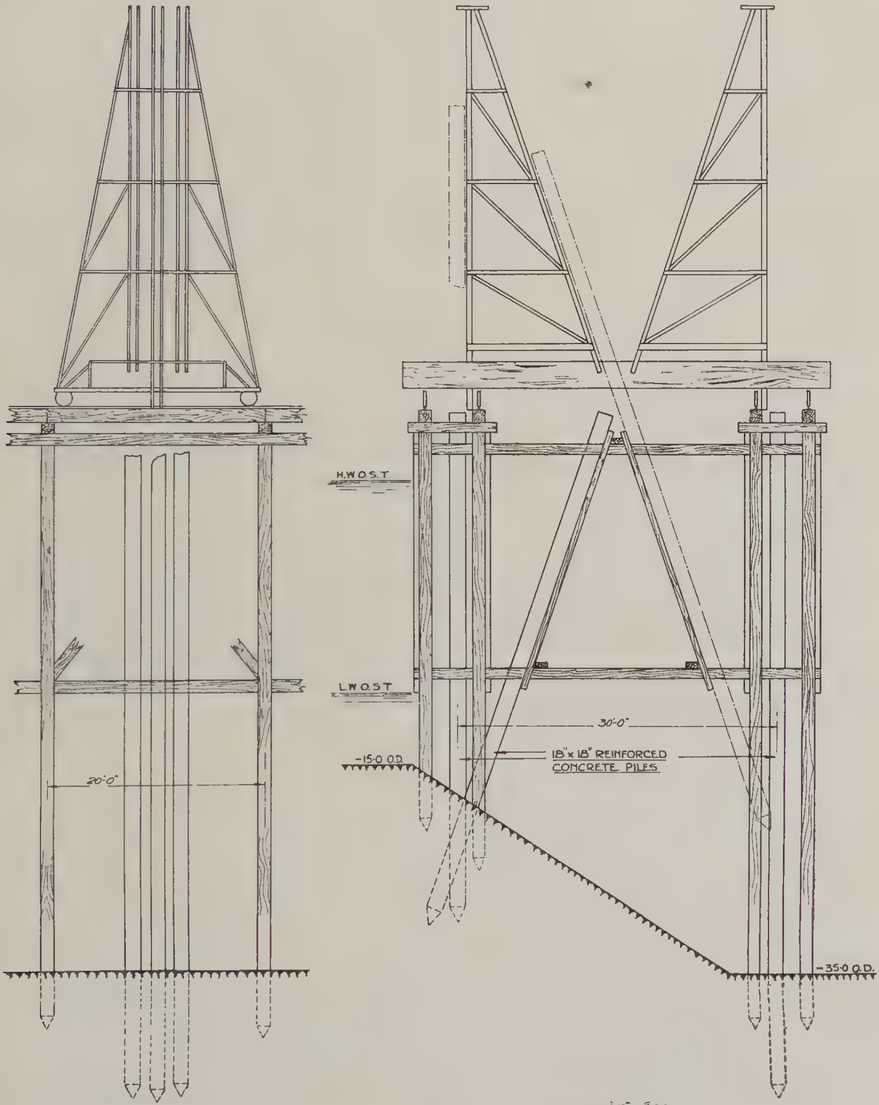


Fig. 459.—Western London Dock, Port of London Authority.

Properly designed reinforced concrete jetty decks show no permanent deflection after a test load has been applied and removed. On a jetty constructed at Port Talbot to carry a working load of 8½ cwt. per sq. ft. a test load of 13·9 cwt. per sq. ft. was applied, i.e., 65 per cent. in excess of the working load and the maximum deflection was only $\frac{3}{16}$ in., the average being ⅛ in.

The permanent deflection after removal of the test load was nil. Beams of 20-ft. span in the approach viaduct designed to carry a 20-ton coal wagon were tested with a 44-ton six-wheeled coupled tank-engine and deflected only $\frac{5}{6}$-in. both with the engine at rest and running over the beam. This deflection represents $\frac{1}{3000}$th of the span compared with the specified limit of $\frac{1}{600}$th. In this case again there was no permanent set on removal of the load.


H.W.O.S.T
L.W.O.S.T
20'-0"
30'-0"
18"x 18" REINFORCED CONCRETE PILES
-15·0 O.D.
-35·0 O.D.

SIDE ELEVATION SECTION

Fig. 460.

Construction.—In jetty construction either an ordinary land pile-frame travelling on a temporary gantry or a floating frame carried on a barge may be used according to circumstances. The piles are usually transported from the mainland on barges and lifted by a crane to the position required in the frame. Special types of frames have been designed to drive both vertical and battered piles (*Fig.* 460).

Pontoons and Ships

In the early fifties of last century a small reinforced concrete boat was constructed by Lambot in France and may be considered the first example of the structural use of reinforced concrete. This boat was in use until the year 1904, a tribute to the care taken in its construction and the suitability of reinforced concrete for structures in contact with water.

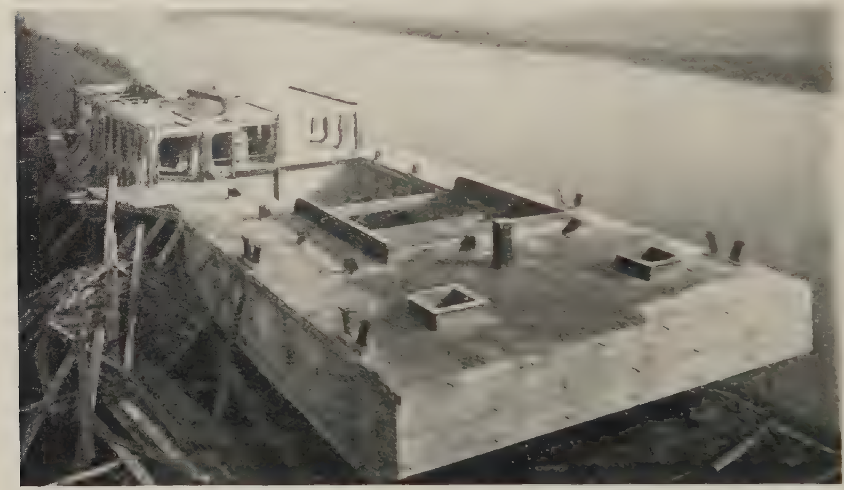


Fig. 461.—200-ton Concrete Lighter on the Manchester Ship Canal.

In more recent times reinforced concrete pontoons have been built to carry the floating ends of landing stages. Lighters and barges have also been built of this material for the transport of coal, dredged materials, etc. In one example 119 ft. long, 22 ft. wide and 9 ft. deep with a capacity of 330 cu. yds., the thickness of the sides and bottom is only about 1½ in. The sides and bottom are also stiffened by internal ribs and partitions.

The design of a pontoon or lighter depends on the relative values of its length, width and draught of water. If it is required to have very thin sides and bottom the slabs span in the direction of the length of the structure and transfer their loads to ribs at frequent intervals. A design with less expensive shuttering may be obtained by regarding the sides and bottom as

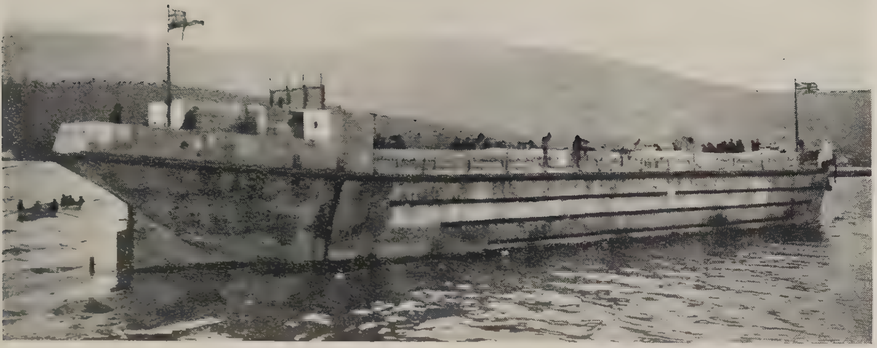


Fig. 462.—A Concrete Ship.

parts of a rigid frame, omitting the heavy ribs, and making the sides and bottom span in vertical and horizontal directions respectively. The latter design suffers from the drawback that watertight bulkheads are not so easily provided.

Formwork.—The details of formwork are similar to those for walls

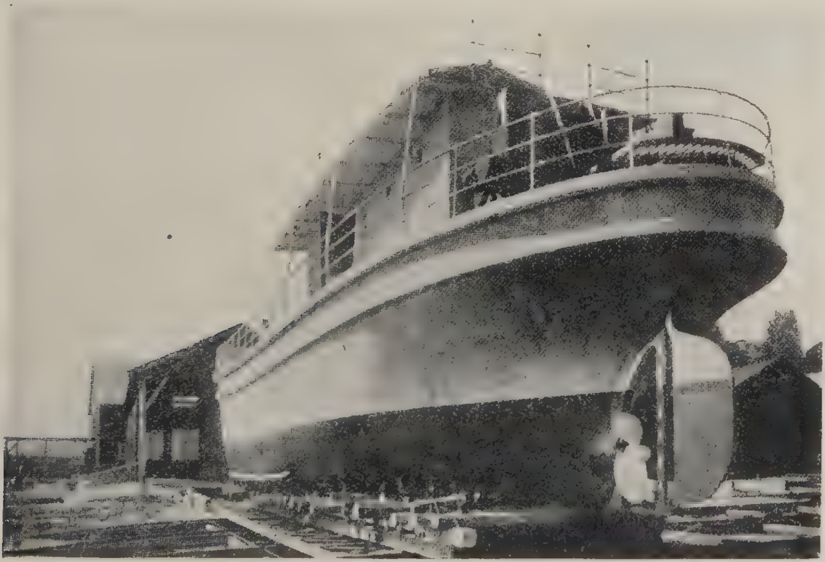


Fig. 463.—1,000-ton Admiralty Concrete Barge.

(see Part IV), but if the barge is built with ship "lines" a large number of special forms will be necessary.

Ample cover is required on the bars and small bars must be used to obtain this in the very thin slabs which are commonly used.

A very dense concrete, and thorough ramming and tamping are essential.

Reinforced concrete pontoons and ships are illustrated in *Figs.* 461 to 463.

Grouting with Cement

The use of cement in the form of grout, i.e., cement to which sufficient water has been added to form a mixture that will readily flow, has of late years reached considerable dimensions. The fixing of holding-down bolts for machinery in brickwork or concrete foundations with liquid cement grout has been practised for many years, but the comparatively recent extension of the same principle to other purposes has now developed to a large extent, and indicates a definite advance in constructional work.

The grouting of the piers of St. Paul's Cathedral is an outstanding example on a large scale of this important development, and the strengthening of the foundations of Winchester Cathedral was an earlier example of a similar method of repair work. In cases such as these liquid cement grout is pumped through small holes bored into old masonry which is known or suspected to contain voids and to be lacking in strength. The cement grout is expected to fill the voids and thus consolidate the loose masses of stone into a monolithic whole. In other cases cement grout is pumped below foundations where additional support is needed.

The sinking of colliery shafts by the cementation method is becoming an important specialist operation, and good service has been rendered to the mining industry by this means. The object in this case is to seal the fissures in any water-bearing strata through which a shaft is being sunk so that water can no longer flow through the ground and impede the sinking operations. For this purpose cement grout is pumped into the ground through small holes. The cement finds its way under pressure into all the cracks and fissures through which water can pass, so that when setting takes place the further flow of water is prevented and the main sinking operations can be carried on in dry strata.

In the boring of oil wells sealing-off with cement grout is also an essential operation in many cases, and successful boring frequently depends upon the efficacy of the cement seal in preventing water rising with the oil to the surface.

The latest example of the application of cement grout on a large scale is in the grouting of roads. The road bed is spread with suitably graded stone and rolled dry. Cement grout, or alternatively dry cement with a copious application of water, is then brushed into the road surface, which is again rolled. The result in this case is that the spaces between the road stone become filled with cement which, on setting, will bind the stone into a concrete. It is not claimed that such road surface equals an orthodox concrete road, but grouted roads are quite satisfactory for secondary roads and several successful examples are in existence.

In ordinary concrete work the use of a minimum of water is regarded as necessary for the production of strong concrete, and as the proportion of water to cement is increased the strength of the concrete decreases at a rapid rate. The importance of keeping the " water ratio " (ratio of water to cement) low is indeed one of the fundamental rules of scientific concrete-making now becoming widely adopted. Hence it is somewhat surprising that such good results are obtained with cement grout in which the " water ratio " is so far above the accepted practice, and it is probably not sufficiently recognised that the successful application of grout largely depends upon the removal of the surplus water which the grout contains. Cement grout may contain 50 per cent. or more of water, which implies that the grout is composed of about 60 per cent. of binding material and 40 per cent. of water which is only a hindrance to the development of strength. If the water remains in the grout after setting, the latter can only set as a honeycomb in which the cells are filled with water ; or if the water is ultimately dried out then the honeycomb has its cells filled with air. Apart from any scientific considerations it is a commonsense conclusion that cement mixed with far more water than can be absorbed must produce a weak mixture. An example of this is given by the following results of tests :

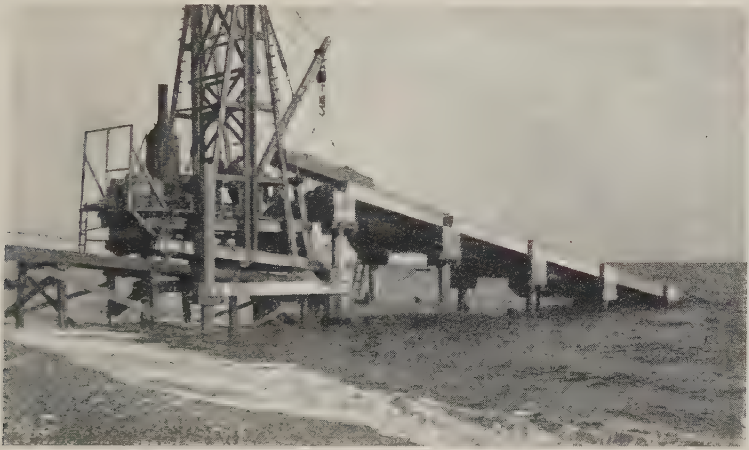


Fig. 464.—Reinforced Concrete Lifeboat Slipway at Selsey.

7 DAYS' TENSILE TESTS WITH NEAT CEMENT.

(*a*) With 23 per cent. water (min. to produce paste), 750 lbs. per sq. in.
(*b*) ,, 40 ,, ,, (,, ,, grout) 450 ,, ,,

It will be obvious that the excellent results obtained with grout in practice are not the result of the reduced strength shown by these tests, and it is a reasonable deduction that the successful use of grout depends upon the removal of the excess water either by absorption, settlement, filtration, or evaporation.

Of these four factors which are useful, if not essential, to the production of successful results from the application of grout it is probable that absorption and settlement are the most usually operative. An experiment designed to show the increase in strength of neat cement grout obtained by removing the excess water by absorption (made by moulding test briquettes of the usual form upon an absorbent base instead of upon the usual iron plate) gives results as follows:

TENSILE STRENGTH AT 7 DAYS OF NEAT CEMENT.

	lbs. per sq. in.
(*a*) Under normal conditions with 23 per cent. water . .	750
(*b*) As grout with 40 per cent. water	450
(*c*) As grout with 40 per cent. water moulded on absorbent base .	770

The strength of cement grout is thus shown to be increased by 75 per cent. and brought up to the normal strength of cement by removal of the excess water by absorption. It is probable that this process of absorption occurs frequently in practice and is the cause of the invariable success that ensues.

In the case of oil-well sealing with cement grout, it is probable that the separation of the superfluous water by the settlement of the cement into a compact mass at the bottom of the bore is the essential to success.

Again, in the sealing-off of water-bearing strata it is not unlikely that some filtration takes place, and the unnecessary water passes away leaving the cement behind to set and harden in a normal manner. In the majority of cases where cement grout is used these means of eliminating superfluous water occur naturally and are taken as a matter of course, but there must be some cases where the necessary circumstances do not exist and it is probable that these are less successful.

In the case of road grouting the excess water may be able to flow away if there is a gradient, or to percolate through a porous sub-grade, and so far as possible it would be a reasonable precaution to provide means for the water to get away.

Various opinions are held as to the qualities of cement suitable for grouting. Quick-setting cement has been specified in some cases in the hope that the grout (which will inevitably be slow hardening, unless the unnecessary water is removed) will have its hardening expedited. This has probably been responsible for some failures arising from the "killing" and disturbance of the initial set of the cement, because the preparation and application of grout cannot easily be completed within the period of the initial set of a quick-setting cement. Quick hardening of grout will be most readily obtained by removal of excess water.

Another quality of the cement which has come under discussion is its fineness. If the grout acquires its strength by the settlement procedure referred to, then a coarsely-ground cement is to be preferred, but if in the sealing of strata the interstices and voids are of microscopic dimensions, then finely-ground cement should be more effective.

Cement Gun

In 1913, after some years of experimenting, the "Cement Gun" was introduced in the United States with the object of spraying surfaces with mortar under pressure. The principle of the method is to pass through a hose by compressed air unhydrated cement mixed with sand. Only when the mixture reaches the nozzle is the water added, by means of a special spray surrounding the nozzle and connected to the source of water supply. The amount of water added may be regulated by the man operating the nozzle. Owing to the material being transmitted through the rubber hose in a dry

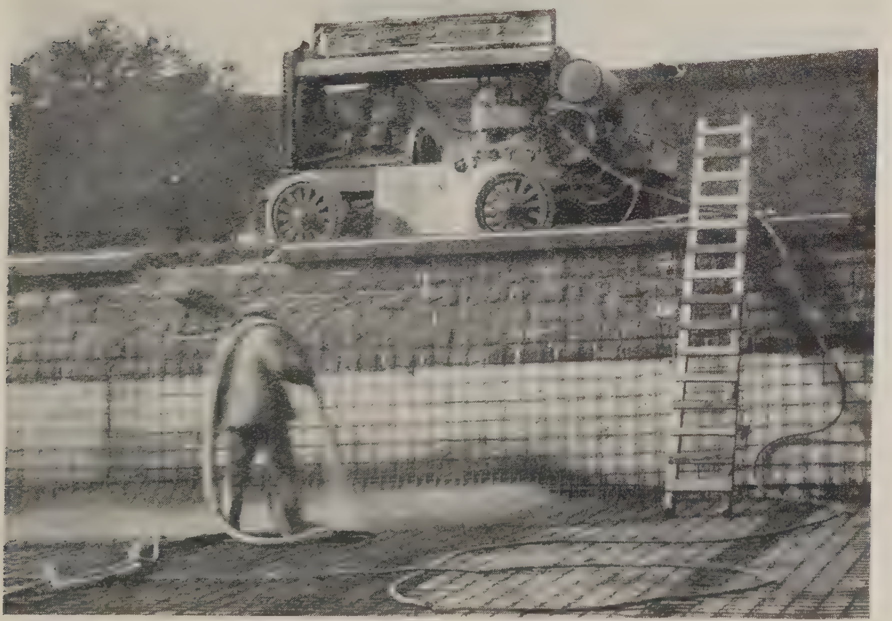


Fig. 465.—Lining Reservoir Floor and Walls with Cement Gun.

state it floats in the current of air and there is very little abrasion of the interior surface of the hose. Lengths of over 500 ft. have been used successfully.

In order to provide a continuous flow of material through the hose the cement gun machine is made in the form of a container with a working chamber and a material lock through which the cement and sand or stone (which may be as large as ⅜-in.) are introduced. The working chamber is constantly under pressure. Both chambers are provided with bell valves operated by hand-levers and may be brought under equal pressure. At the bottom of the working chamber is a feed-wheel by means of which the material is supplied to the hose.

The advantages of the sprayed mortar, known as "Gunite," are its high density and adhesion and its watertightness. Owing to the fact that gunite hardens more rapidly than ordinary mortar, forms, if any are required, can be removed quickly. The total labour required comprises one man to operate the cement gun, one nozzleman, three men mixing material, and one general labourer.

PART V

CONCRETE ROADS

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CONCRETE ROADS

At the end of the year 1929 there were 1,000 miles of all-concrete roads in Great Britain. Of this total 137 miles were built in 1927, 200 miles in 1928, and about 250 miles in 1929. These figures are based on a width of 20 feet. When it is remembered that it is only a very few years since the all-concrete road received serious consideration in this country as a solution of the problem brought about by the ever-increasing speed and weight of road transport, it can safely be said that up-to-date County and Borough Engineers and Surveyors and others responsible for road construction and upkeep have thoroughly realised the advantages of this type of road. Concrete or reinforced concrete is, of course, always used for foundations carrying wood blocks, asphalt, setts, or other surfacing, and is recognised as being indispensable for all thoroughfares taking heavy traffic.

The use of unsurfaced concrete has the advantage of dispensing with the initial cost of surfacing and consequent saving in maintenance costs. It has, however, its own special problems which must be solved if satisfactory results are to be obtained, and in this Part are described the methods of construction that have been found as a result of experience to produce an all-concrete road with good wearing properties and freedom from cracks.

It is desirable that a concrete road surface should have four qualities, namely, (1) strength to bear the loads it has to carry without fracture, (2) resistance to the wear arising from wheeled and horse traffic, (3) freedom from cracking, and (4) non-skidding properties.

With regard to the first-mentioned quality of strength, this is a matter of design which presents no difficulty to the concrete designer. The next quality is resistance to wear, and this is probably the stumbling-block to those without experience. It may in fact be admitted that this is the most critical condition upon which concrete roads must stand or fall. The road engineer requires to know what is necessary to make concrete wear-resisting, and the reply is the one word "quality." It is as important that the aggregate should be of good quality as that the cement should be good British Portland cement. The conditions that produce a strong and therefore wear-resisting concrete are well known, and may be summarised as a proper proportion of cement, no excess of water beyond that required to produce a plastic concrete, graded clean aggregate, thorough mixing, proper

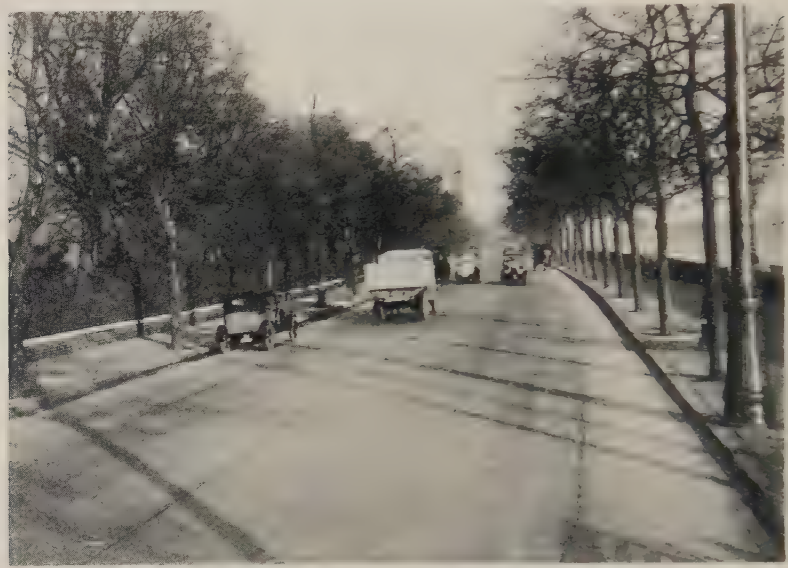

Fig. 466.—Chelsea Embankment, London, Concrete Section.

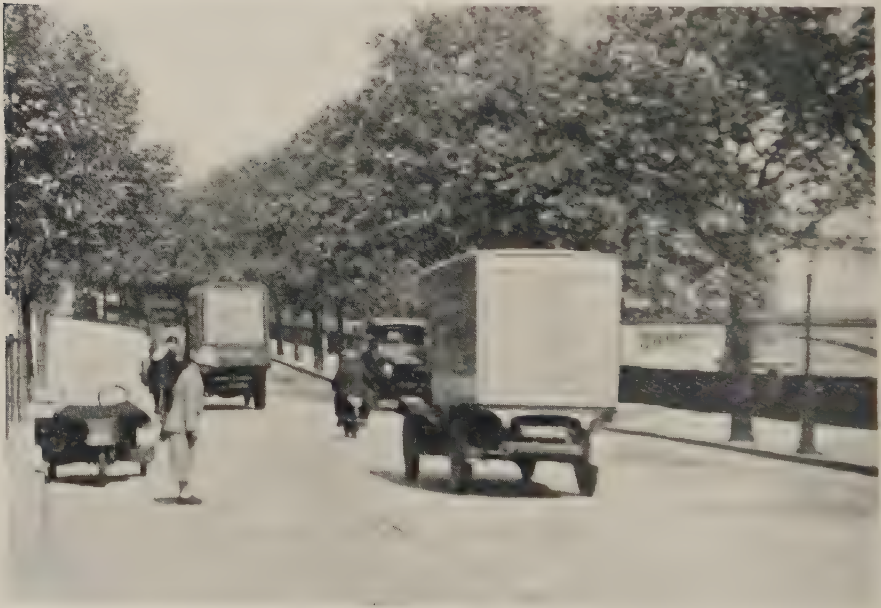

Fig. 467.—Chelsea Embankment, London, Concrete Section.

curing (i.e., keeping the concrete damp during the period of early hardening), and age. A further assurance can be obtained by applying to the surface of the road a surface hardener, such as sodium silicate solution. Such treatment also has the advantage of accelerating the hardening of the concrete.

The third quality needed in concrete roads is freedom from cracking. Cracks are primarily due to contraction of the concrete. In continuous construction these cracks seem bound to appear in any position of exposure to sun or frost, even though proper precautions in curing the concrete are taken. This led engineers to examine what is known as the alternate bay method of construction, and it appeared at first that this might be a success. However, with normal construction, cracks appeared with alternate bay construction roughly along the centre line and zig-zagging to the right or left. Later experience seems to suggest that these may be prevented in this form of construction either by thickening the centre of the road or introducing reinforcement into the middle third.

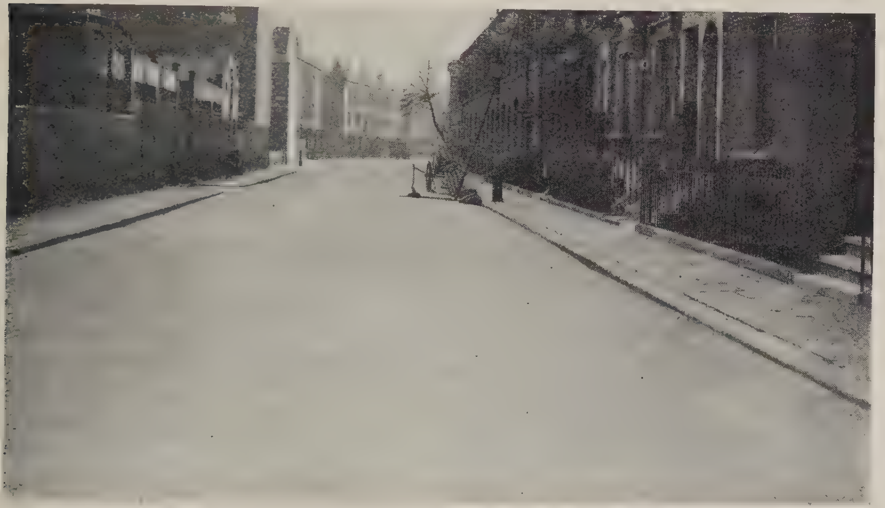

Fig. 468.—Delverton Road, Southwark: A London Concrete Road.

Another even more successful method of preventing cracks appears to have been obtained by laying the concrete road in longitudinal strips not exceeding 15 ft. in width. If the bays are not reinforced then they must not measure more than 20 to 30 ft. in length, but where reinforcement is used it appears possible to extend this to 50 or even 60 ft.; this reduces the number of transverse joints in the road, and is therefore preferred by some engineers. The Middlesex County Council has already constructed a test road on this system, but it is too early to give any results of the experiment as the road has not been constructed long enough to be exposed to all seasons of the year.

Diagonal joints have been tested in various parts of England and seem to have their advantage where alternate bay construction has been adopted, but this advantage is not apparent when the strip method is adopted by reason of the fact that it introduces a weak angle in the centre of the road which may give rise to corner breaks. It is, therefore, possible that future practice will lay down that diagonal joints shall not be adopted for this latter method of construction. So far experience seems to show that the strip method gives a smoother riding surface than the alternate bay method.

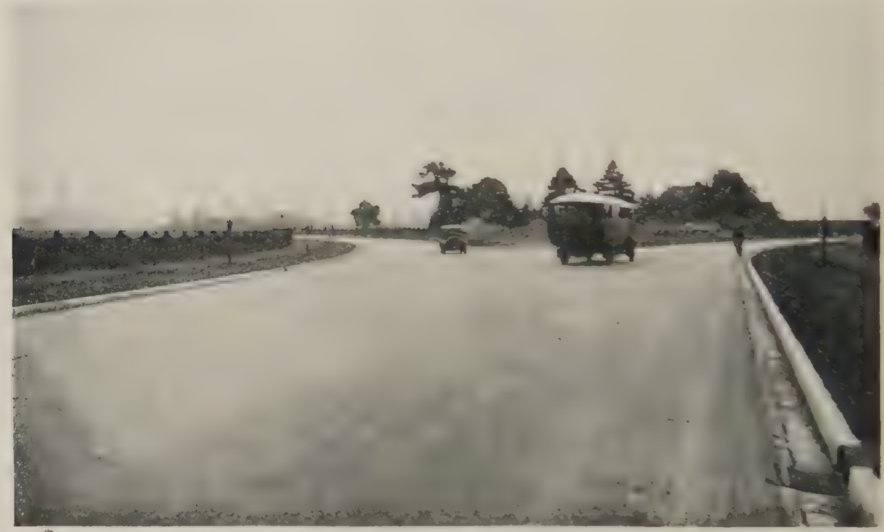

Fig. 469.—Priory Road, Lichfield : A Concrete Surface.

In these days of fast motor traffic a non-slippery surface is of the utmost importance, and bare concrete is undoubtedly, by the very nature of the materials of which it is made, an assurance against slipping, for broken stone and sharp sand are in themselves gritty. It has, in fact, been proved to be practically impossible to skid a car on a bare concrete surface.

One of the chief advantages of the bare concrete surface is the fact that gritting can be dispensed with. It may be necessary if there is a very heavy frost and ice is formed over the road, but generally speaking it is not required. This is of importance in towns as, if it costs about a penny a square yard to grit the road, and it is gritted 30 times a year, no less than 2*s*. 6*d*. a sq. yd. can be saved each year. More than this, saving is effected when it is remembered that the greater portion of this grit eventually finds its way into the sewers from which it has to be reclaimed and dumped.

Regarded from a common-sense standpoint, then, the secret of success with concrete roads is to employ strong concrete and careful workmanship ; every precaution that can be taken to ensure good concrete will justify itself in the life of the road.

The Bates Road Test.—With a view to obtaining at first-hand definite knowledge as to the type of road best able to carry successfully modern traffic, the Illinois State highway officials decided in 1920 to lay an experimental road consisting of various forms of construction, and test it until it was destroyed. This was done. The road consisted of sixty-three sections, each from 100 to 250 feet in length, laid end to end so that they formed a continuous straight road about two miles long. Twenty-two of these sections were of brick, seventeen of asphalt, and twenty-four of concrete.

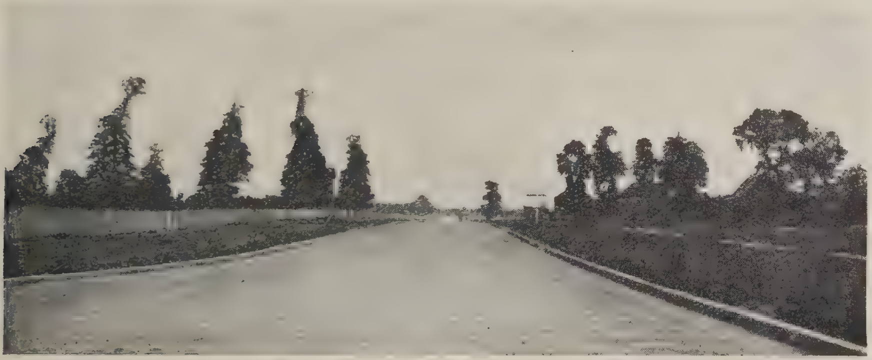

Fig. 470.—Great West Road, Staines : Concrete Surface Section.

The tests were begun in March, 1922. The traffic consisted of 12 to 18 three-ton army trucks equipped with solid tyres. The trucks made regular, timed trips along one side of the road and back the other, the total number of round trips being 23,000. Beginning with the bare chassis and cab, loads were increased until a gross load of 12¼ tons was reached. Fifty of the sixty-three sections were either partially or entirely destroyed. Of the thirteen which survived the test, ten were all-concrete roads, and the remaining three had concrete foundations with a surface of other material. Of the ten all-concrete sections which survived, seven were reinforced. The reinforced sections varied in thickness from 5 to 7 in., while the unreinforced sections were 8 and 9 in. thick. The concrete in all the concrete sections was a 1 : 2 : 3½ mixture. The Director of the Department of Public Works and Buildings, the Superintendent of Highways and the Chief Highway Engineer were in charge of the test. This test, carried out by disinterested and impartial authorities under uniform test conditions, conclusively proved that the concrete road is the one best fitted to meet the demands of modern traffic.

Resistance to Impact.—One of the essentials of a good road is that it must be level. Most roads are even when they are first made, but the ideal road should remain level, and not work into waves or develop potholes. It has been found as the result of experiment that for every inch the wheel drops from the crest of a wave to the trough, the force of the impact can be anything up to 400 per cent. greater than the load. The concrete road, however, begins by being level, and remains level, and so ensures a minimum of impact and therefore a minimum of wear and tear upon the vehicles which use it. This contributes to the conservation of power, and the greater efficiency and longer life of the vehicles using the road.

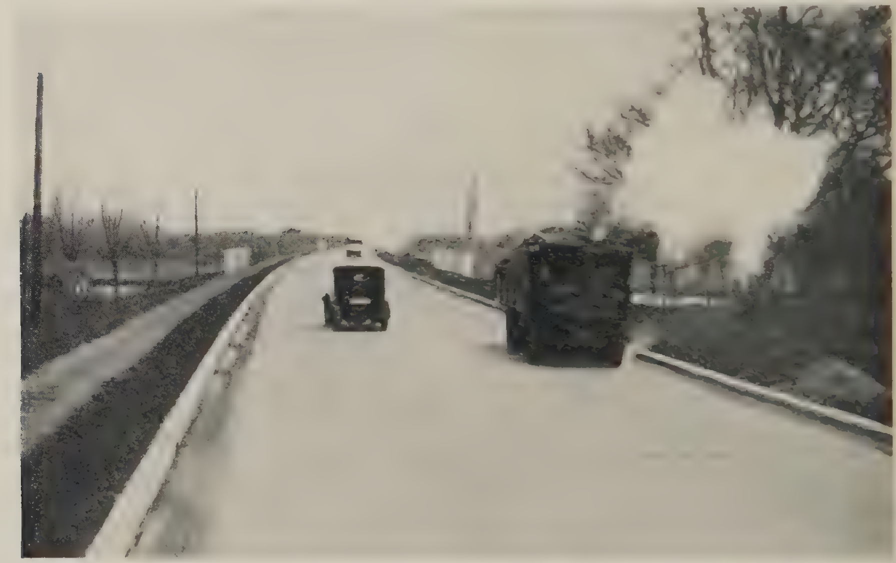

Fig. 471.—London and Bath By-Pass Road : Concrete Surface Section.

Low Tractive Resistance.—The low tractive resistance offered by unsurfaced concrete was demonstrated very conclusively by a series of tests carried out under the auspices of the University of California, and at Cleveland, Ohio, with a view to ascertaining the amount of force necessary to keep a loaded vehicle in motion after it had been started, and the distance fully-loaded trucks could travel per gallon of petrol. In the result

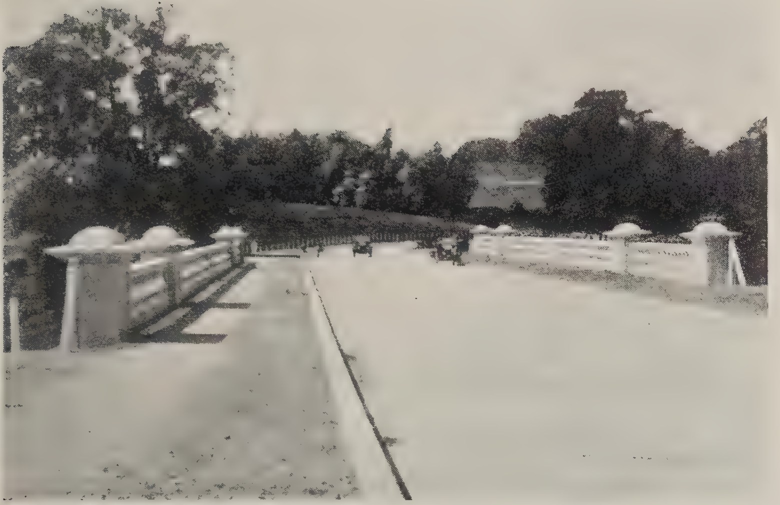

Fig. 472.—Concrete Road and Bridge on the East and West Road, Surrey.

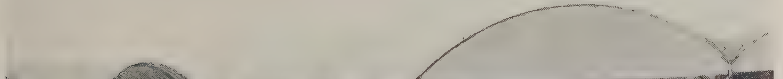

Fig. 473.—Reinforced Concrete Works Road near Market Drayton.

it was found that, whereas the force required on some types of road in good condition was 64 lbs. per ton, on unsurfaced concrete it was only 28 lbs. per ton; the result also showed that similar trucks fully loaded could travel 11·78 miles per gallon on a concrete road as against 9·48 and 9·39 miles on level roads of other types in good condition.

Roads in Industrial Works

Concrete roads are now being generally adopted as approach roads to factories, warehouses, and other industrial concerns. Several hundreds of concrete roads have been laid down in works of all descriptions—engineering works, rolling mills, gas works, breweries, collieries, tanneries, oil manufacturing centres and distributing stations, confectionery works, photographic material factories, and many others. Wharves on the Thamesside have been laid in concrete, and although the traffic, consisting mainly of fully-loaded steam lorries, amounts to 300 tons a day, there is not the slightest sign of wear.

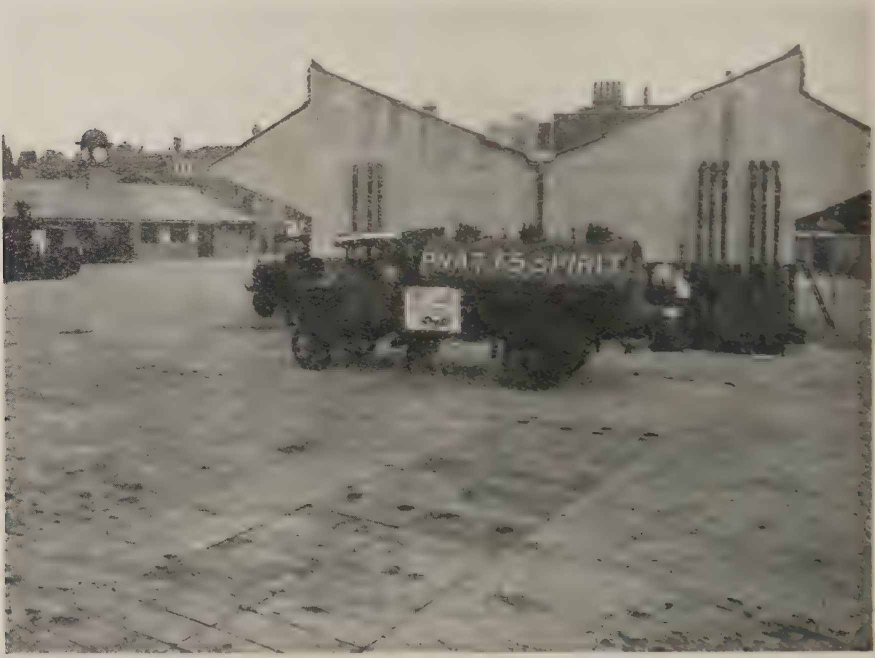

Fig. 474. Albert Embankment Concrete-Surfaced Depôt of the Anglo-American Oil Co., Ltd.

Housing Scheme Roads

Where concrete roads are adopted for housing schemes they are usually laid first, and carry all the building traffic without deteriorating in any way. When each scheme is complete the Surveyor takes over the road as a completed road, and the frontagers are charged with a known cost. Concrete is the only material which enables this to be done.

Roads on Private Estates

The advantages of concrete for public roads and streets also apply to private roads—farm roads and the like—which often have to carry fairly heavy traffic. On one estate, the Hales Estate, Market Drayton, a concrete roadway 2¼ miles long has been constructed. This was designed to improve the communication between the farms on the estate and the public roads, and has been found a great boon. A breeder of prize cattle in Kent says that his concrete roads have been the salvation of his farm, as without them he could not have continued. This, which is an entirely unprejudiced opinion, formed as the result of experience, speaks for itself.

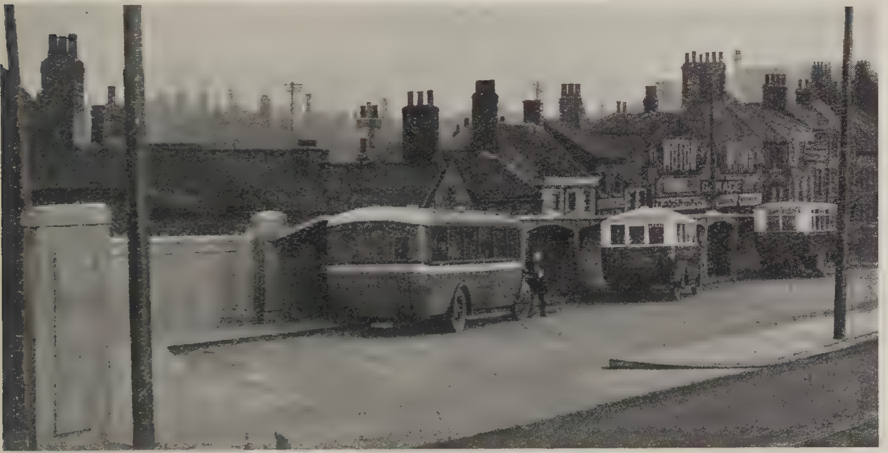

Fig. 475.—Concrete-Surfaced Omnibus Stand and Shelter, Doncaster.

The great economies to be effected by the use of concrete for private roads, housing scheme roads, etc., are clearly shown by the following figures of such roads actually built or for which tenders have been called. It will be seen that there is actually an initial saving in construction costs, in addition to greatly reduced maintenance expense.

Concrete was shown to effect a saving of 10 per cent. over flint and 15 per cent. over tarmacadam.

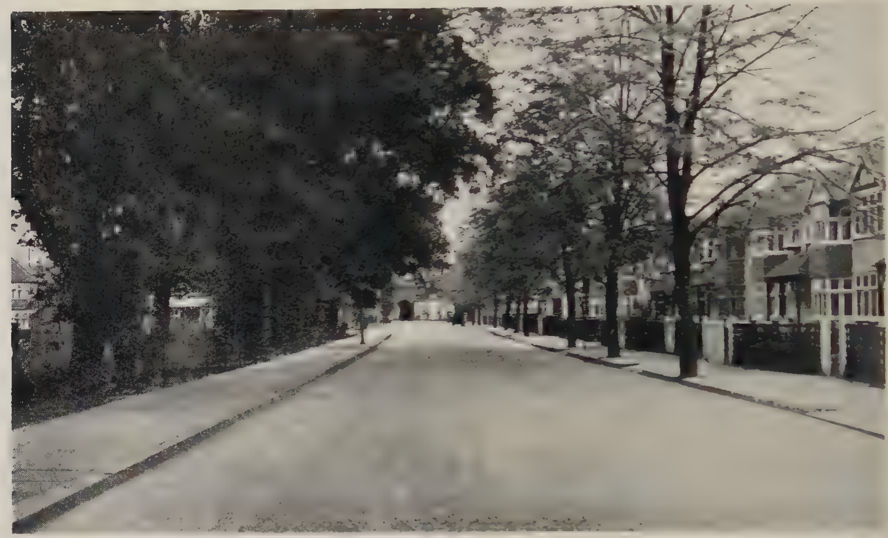

Fig. 476.—Grand Drive: A Concrete Road at Raynes Park.

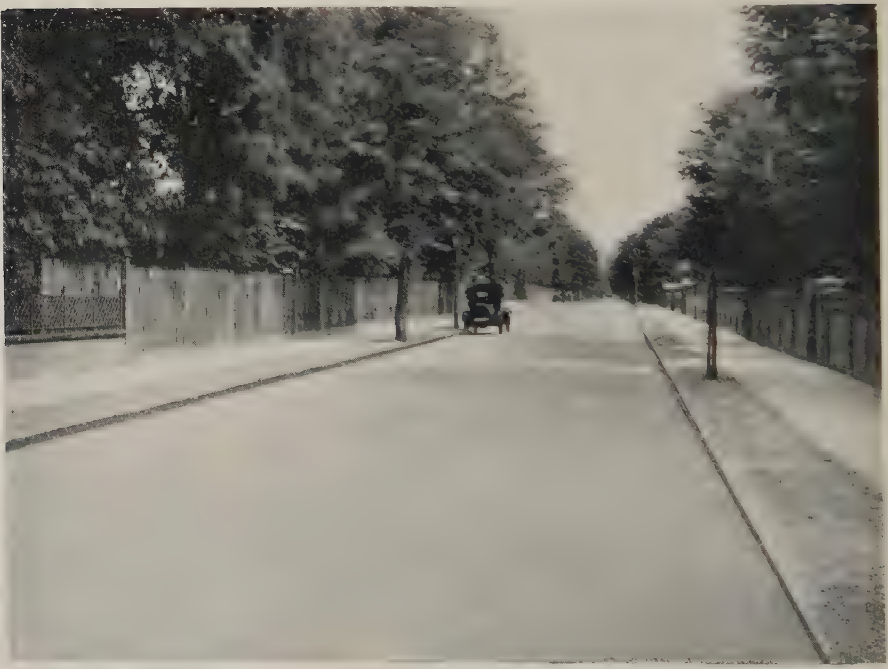

Fig. 477.—Fairfax Road: A Concrete Road at Teddington.

Borough of Acton.—Lowest alternative tenders for concrete and tarmacadam for different carriageways :

6-in. Concrete.			4-in. Tarmacadam.		
£	s.	d.	£	s.	d.
1,756	5	6	1,845	6	6
1,490	0	11	1,706	8	4
628	4	0	704	6	7
5,125	0	0	5,854	0	0
2,858	1	0	3,294	3	7

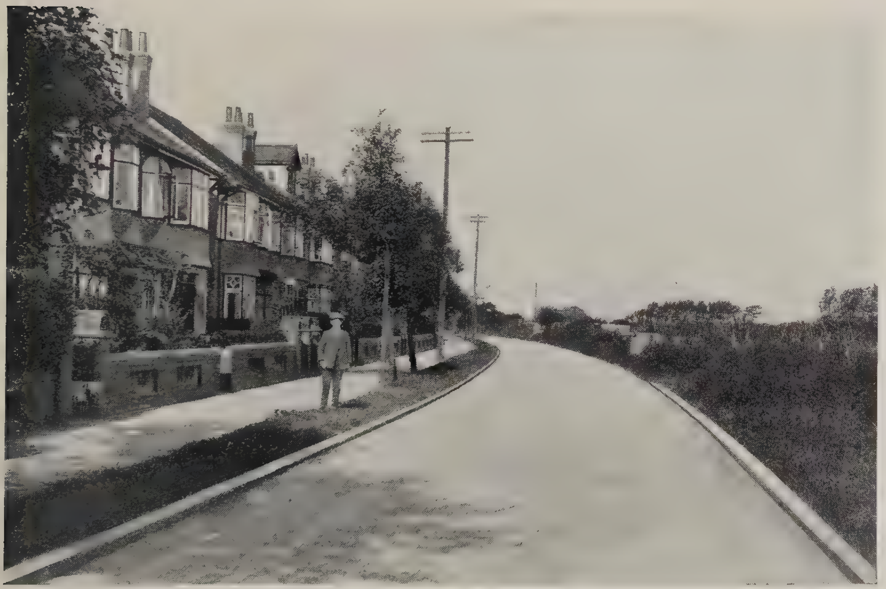

Fig. 478.—A Concrete Private Street at Hoylake, Cheshire.

Teddington U.D.C.—Recent contract prices for 6-in. reinforced concrete carriageway, 8*s.* 7*d.* per yd. super.

Chesterfield R.D.C.—Average tender for concrete, £983 ; average tender for slag, £1,003.

Brentford and Chiswick U.D.C.—Lowest concrete tender, £1,369 ; lowest tarmacadam tender, £1,728.

Lewisham.—Lowest tender for concrete, £595 ; lowest tender for flint, £670. Shell Road : Flint carriageway, £1,406 ; concrete, £1,391. Pearfield Road : Flint, £1,408 ; concrete carriageway, £1,393.

Wandsworth.—Lowest tender for ten streets in concrete, £18,048 ; lowest tender for tarred slag on hardcore, £20,174.

Woodford U.D.C.—Waterbound granite carriageway, average tender £802 10s. 6*d.*; concrete carriageway, average tender £692 8*s.* 2*d.*

Epsom.—Macadam construction, 13*s.* 2*d.* per sq. yd; concrete construction 9*s.* 11*d.* per sq. yd.

Friern Barnet U.D.C.—Reinforced concrete carriageway, 20*s.* 10½*d.* a foot frontage; tarmacadam, 28*s.* 4½*d.* a foot frontage.

Southall and Norwood U.D.C.—Road A (tarmacadam carriageway): 9 in. hardcore, 4 in. tar slag macadam, rolling, etc., 10*s.* 1*d.* per super yard of carriageway. Road B (two-course concrete carriageway): 3 in. ashes, 6 in. reinforced concrete, expansion joints, 9*s.* 11½*d.* per super yard. Road C (two-course concrete carriageway): 3 in. ashes, 6 in. reinforced concrete, expansion joints, 9*s.* 3*d.* per super yard.

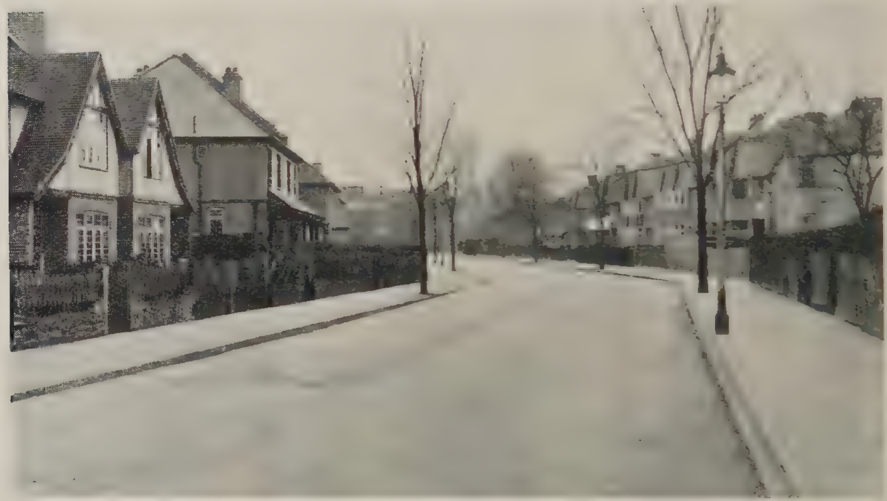

Fig. 479.—Elmsfield Avenue: A Concrete Road at Teddington.

Rough-Surfaced Roads

On gradients where horse traffic has to be seriously considered many would prefer a water-bound macadam surface. A similar surface, but of a far more durable nature, may be obtained in concrete by using large stone aggregate in the surface—cubical granite or whinstone for preference. Just before the cement has set, the grout is swept out from the interstices. This leaves the stones projecting, and thus a good foothold for horses is secured. Concrete roads of this kind have been laid on gradients as great as 1 in 6. A road of this description at Portsmouth is shown in Fig. 480.

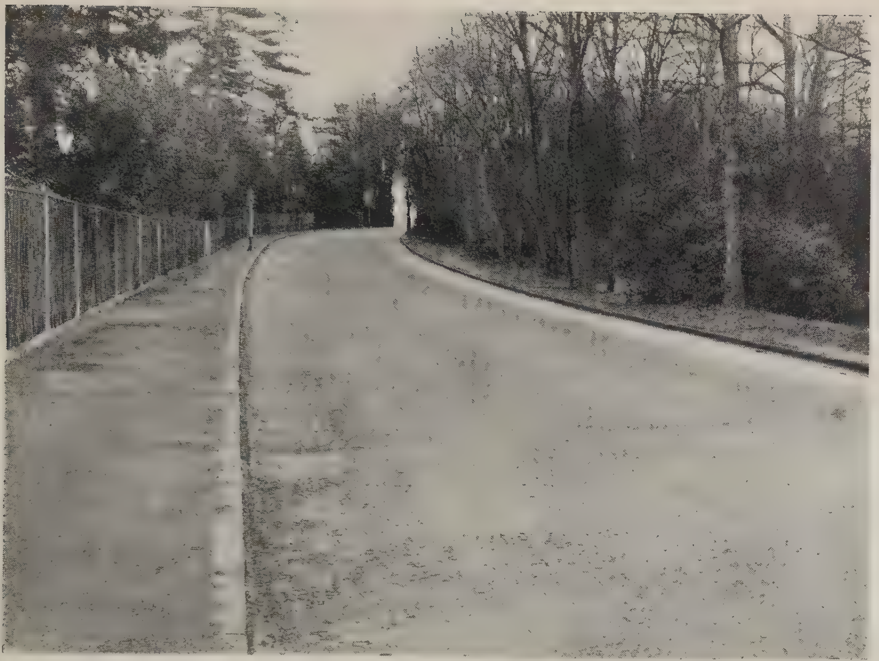

Fig. 480.—Concrete Road on Hill : Portsmouth Road.

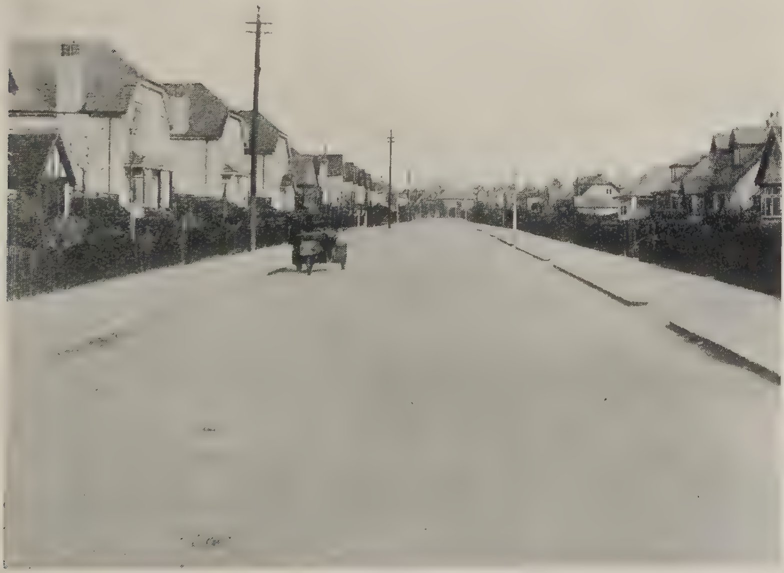

Fig. 481.—Cotsford Avenue, New Malden : A Private Street in Concrete.

Pre-cast Concrete-Block Roads

Wherever it is difficult to get water or aggregates for highway construction, or where it is necessary that the traffic be maintained without interruption, the laying of pre-cast concrete blocks or slabs offers many advantages, and by the use of such blocks a road can be constructed which possesses one advantage over *in situ* concrete, namely, that the blocks can be thoroughly matured before they are used in the road. The result is that roads can be opened to traffic as soon as the bedding and jointing mortar have hardened, which is in seven days if ordinary Portland cement is used, three days if rapid-hardening " Ferrocrete " Portland cement is employed, and one day by the use of " Lightning " brand aluminous cement. These road blocks may be of any practical shape, but rectangular and hexagonal are generally used.

Fig. 482.—A Concrete Back Street.

A system of hexagonal block construction for concrete roads is that patented by Mr. J. E. Cardell, A.M.Inst.C.E., Divisional Surveyor of the West Riding County Council of Yorkshire. In this system, the blocks, which are of such thickness as to meet the requirements of each individual case, are provided with grooves on the underside for the reception of steel bar reinforcement, which is held in position and firmly united to the blocks by means of cement mortar, the whole being bedded on cement mortar. The blocks are compacted by hydraulic pressure and matured under cover before being put into use. In this way a dense concrete is obtained, the blocks are true to shape, with sharp arrises, close joints are obtained, while the shape and arrangement of the blocks ensure that there are no joints transverse to the axis of the road, and so wheeled traffic passes from one block to another without shock.

A section some 2,000 square yards in area has been paved with these blocks on the main road near Standedge in the West Riding of Yorkshire, an adjoining section of approximately equal area having been laid at the same time in granite setts on reinforced concrete. This road forms part of the trunk route from Liverpool, via Manchester and Leeds to Hull, and the traffic census at the nearest census point gave a tonnage of some 5,000 tons per day.

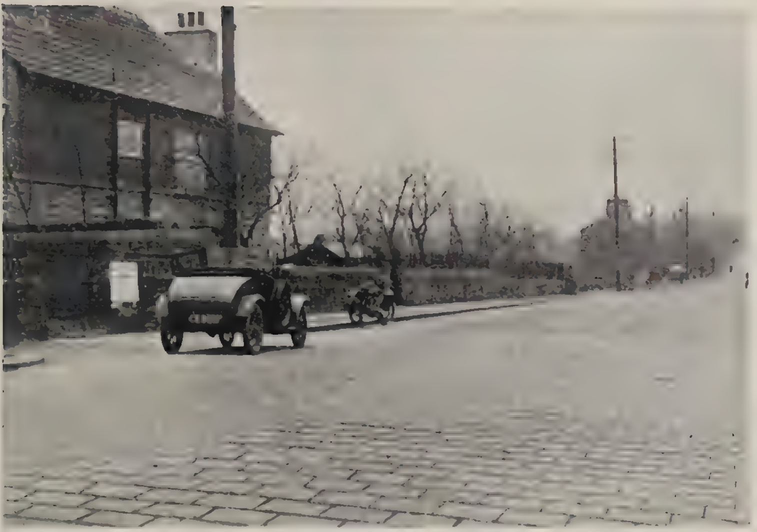

Fig. 483.—Pre-cast Concrete Block Road at Lightcliffe.

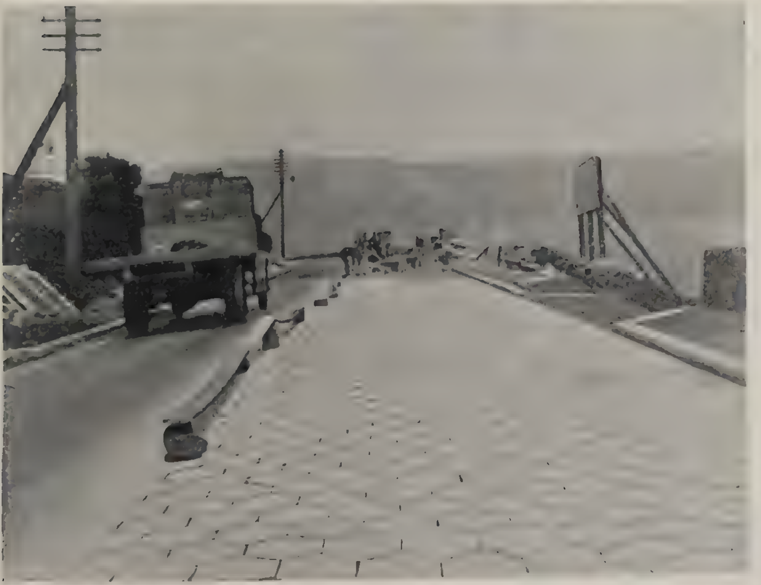

Fig. 484.—Hexagonal Concrete Block Road near Standedge.

The cost of a concrete road varies, of course, according to the nature of the site, cost of materials, rates of wages, etc., in different localities, but from the following figures, relating to a recently laid road in a rural area, it should be possible to estimate the approximate cost in any district by making allowances for differences in the price of materials and wages, and increasing or decreasing the sum for excavating and grading according to the condition of the site.

	Cost per yard super of road 6 in. thick.			
	s.	*d.*	*s.*	*d.*
Excavating and grading*	0	8		
Rolling sub-base to camber	0	4		
			1	0
Aggregate (sand and ballast) at mixer, at 12*s.* per cb. yd.	2	10		
Cement (1 : 2 : 4 mix), at 50*s.* per ton	2	0		
Labour: Mixing, screeding and finishing, at 1*s.* 2*d.* per hour	1	6		
Supplying and fixing forms, etc.	0	4		
Watering, watching and curing	0	4		
			7	0
Total			8	0

* If laid on an existing road, this item would be reduced to 6*d.*, or even less. Where reinforcement is used, this would cost about 1*s.* 2*d.* per yard super laid. Average price of reinforcement, say, 1*s.* per square yard.

Notes on Construction

So much depends on the nature of the soil and the traffic to be carried that it is impossible to lay down any hard and fast method for the construction of an all-concrete road. The following notes, however, give the general practice now followed in this country.

Materials.—The cement is such an important factor that it is essential that it should be British Portland cement complying with the requirements of the British Standard Specification, and should be slow-setting cement. Slow-setting cements include rapid-hardening Portland cements.

Care should be taken in the selection of the aggregates. No natural deposits of sand and gravel should be used without washing, screening, and grading. If crushed stone is used it should be screened, graded, and, if necessary, washed. No aggregate should be used which is not hard and tough, or which is laminated and upon crushing breaks down into flat or elongated particles. Soft or porous materials, such as broken brick, breeze, etc., should be prohibited. All aggregates used must be clean and free from clay, dust, vegetable and other foreign matter. Care must be taken that the aggregate is not contaminated with mud, etc., after delivery to the site of the work.

For one-course roads no aggregate should be used which will not pass through a screen having circular openings of 2½ in. for a 6-in. road or 3 in. for an 8-in. road. None of the coarse material should pass through a ⅛-in. square opening. The grading from the maximum to the minimum sizes should be regular, and no material should be used which contains a large proportion of stones of approximately one size. Chippings for the upper course of a two-course road should be graded from $\frac{3}{4}$ in. to $\frac{1}{4}$ in.

Sand or fine material should pass through a $\frac{1}{8}$-in. square opening, but not more than 20 per cent. by weight should pass a sieve having 50 meshes per lin. in. The grading from the maximum to the minimum sizes should be regular, and no material should be used which contains a large proportion of particles of approximately one size.

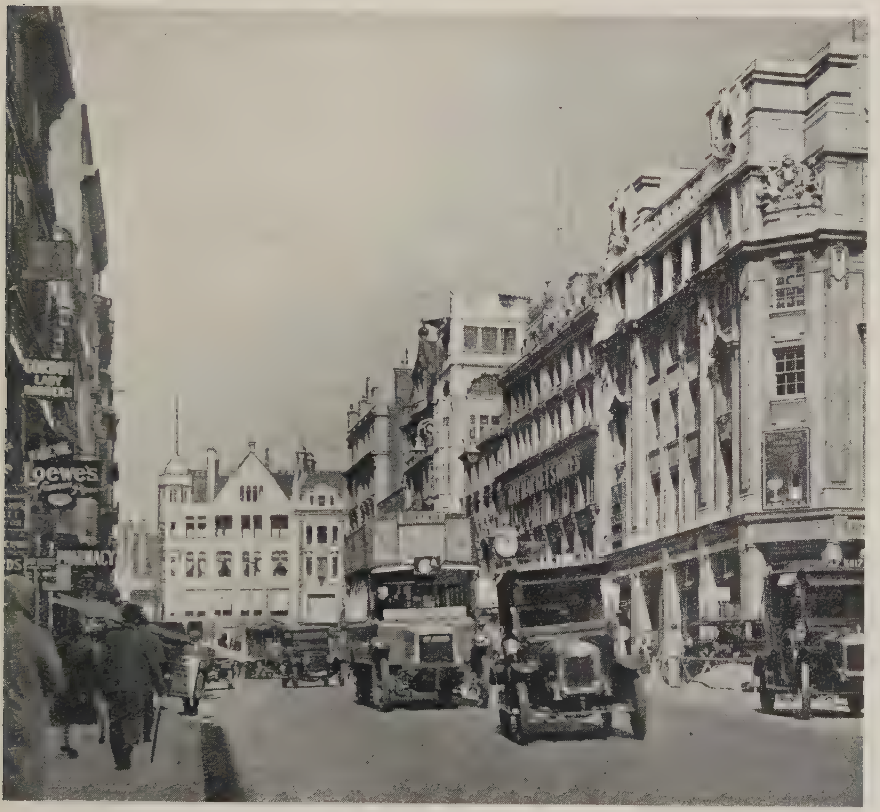

Fig. 485.—Haymarket, London: Concrete Foundation.

The average crushing strength of the concrete should be about 3,000 lbs. per sq. in. at 28 days for a 1 : 2 : 4 concrete with ordinary Portland cement, or 2,000 lbs. at 7 days with rapid-hardening Portland cement. For determining the compression resistance, tests should be made on cubes or cylinders of not less than 6 in. each way, composed of concrete which as far as possible conforms to the conditions that will obtain in the actual execution of the work. The water must be fresh and clean. Expansion joint filler must be a fibrous, elastic, waterproof material, which will not lose these properties under extremes of weather conditions.

Preparation of Subsoil.—The preparation of the foundation will necessarily vary with local conditions. Any necessary embankments or fills should be thoroughly consolidated, so that there is no possibility of settlement at any point. Any soft or weak places must be excavated and filled with hard stone or other suitable material, so as to obtain solidity equal to the remainder of the surface. The surface should be finally rolled to the required contour with a roller of not less than 8 tons in weight. The surface thus prepared must be regular, either flat or with a slight cross fall. Immediately before the concrete is placed, all foreign matter must be removed from the prepared surface, which must then be thoroughly watered.

Fig. 486.—Pall Mall, London: Concrete Foundation.

Concrete.—For one-course roads 1 part cement to 6 of fine and coarse material appears to give the best results. For the lower course in two-course roads the volume of coarse and fine aggregate when mixed should not exceed six times that of the volume of the cement. The proportion of 1 : 2½ : 5 has given satisfaction. For the top course a mixture not weaker than 1 : 2½ : 3 (chippings) is recommended.

It is perhaps not wise to specify, except in a general sense, the proportions of the mix, in the ratio of fine to coarse aggregate. It would be safer to give the ratio of cement to fine and coarse aggregate combined and then decide on the job, by the void test, the actual ratio between the fine and coarse aggregate.

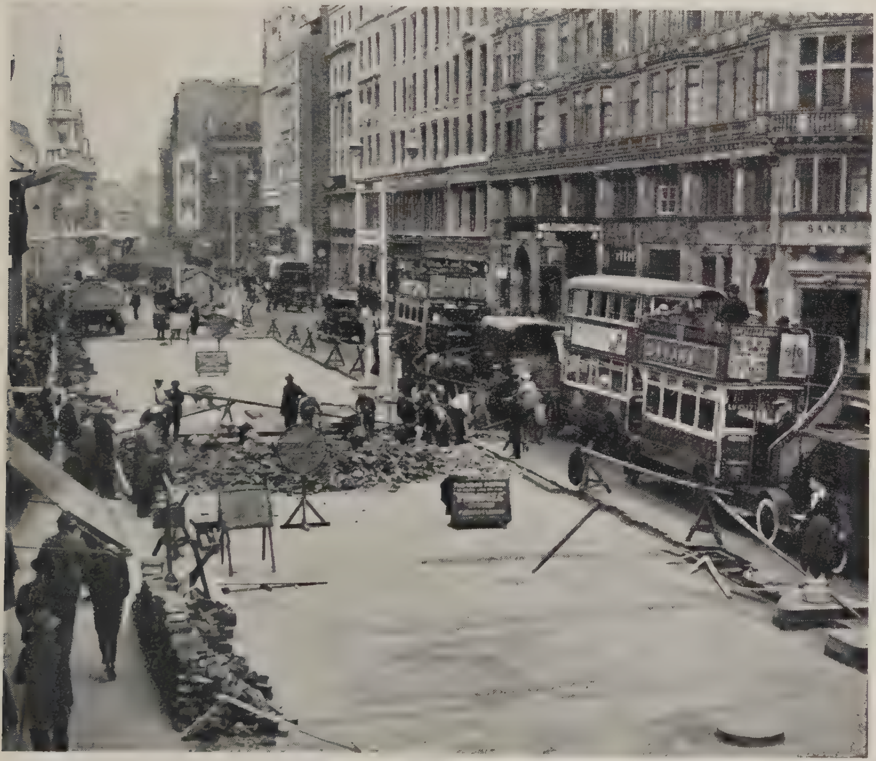

Fig. 487.—Strand, London : Concrete Foundation.

The concrete should preferably be mixed in a batch mixer, and mixing must continue until the ingredients are homogeneous and plastic throughout. The drum must be completely emptied after mixing each batch. The quantity of water should be such as to secure a plastic mixture. The slump test (see p. 56) is recommended to secure a consistent mix. The maximum

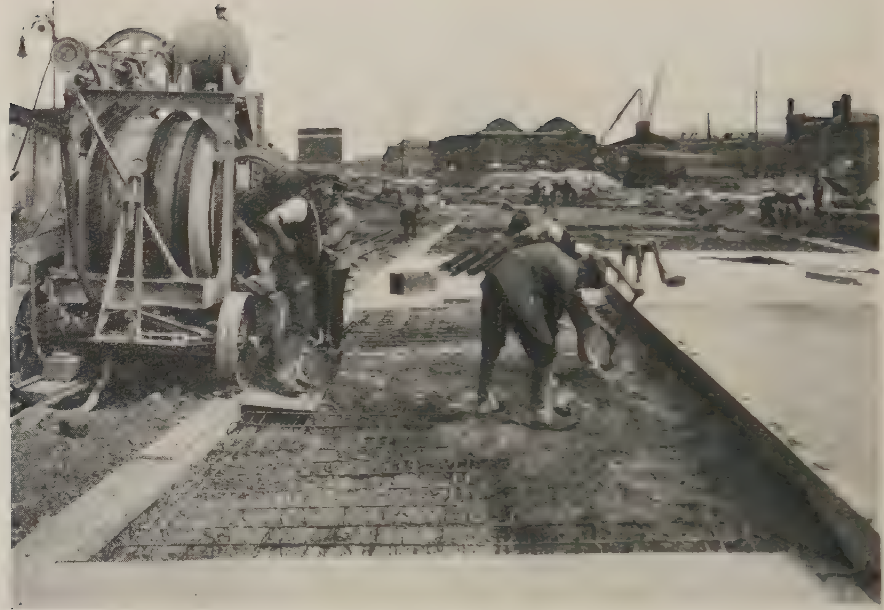

Fig. 488.—West India and Millwall Docks: Concrete Surface Areas.

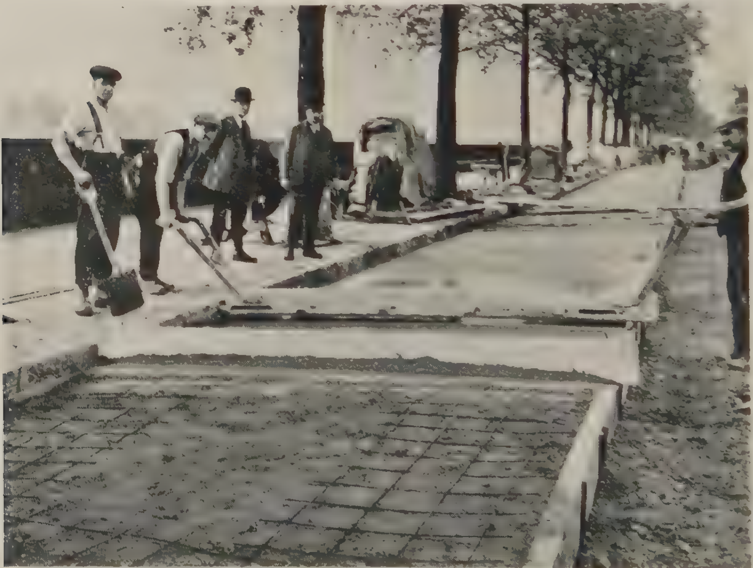

Fig. 489.—Combined Tamper and Screed for the Top Course.

slump desirable is about 1 in., or as the engineer may have pre-determined. This will prevent an excessive amount of water being used, and the concrete will not be so sloppy as to cause a separation of the coarse aggregate from the mortar during handling and laying. Any concrete which has partially set before being placed in position should not be used.

So far as is practicable, all work should be done between temperatures of 35 deg. and 75 deg. F., but in the event of concrete roads having to be laid when the thermometer is below 35 deg. F., care should be taken that all materials used are free from frost, and the completed work must be protected from freezing. It is essential that the concrete be protected against the sun's rays, especially when working in temperatures above 65 deg. F.; it should also be protected from drying wind, irrespective of temperature. Cracks are inevitable if this precaution is not taken. When night frosts are prevalent a sufficient quantity of material should be protected to enable the next day's work to start promptly.

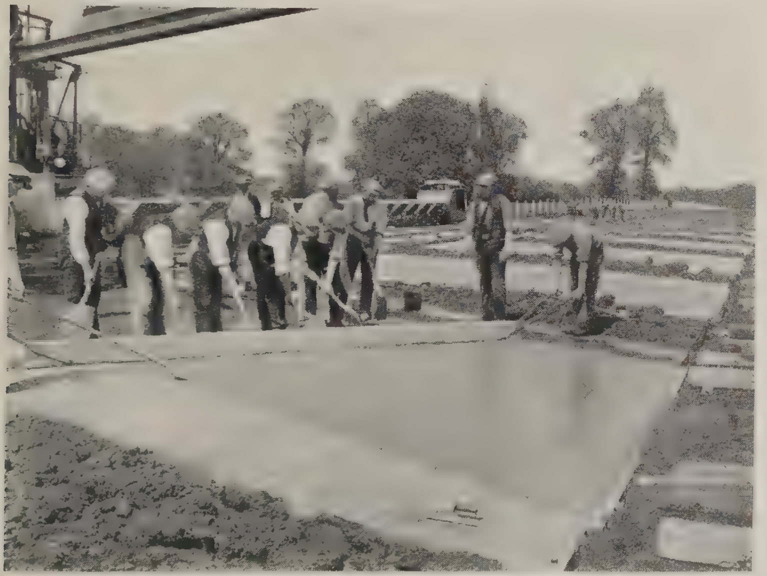

Fig. 490.—Alternate Bay Construction, showing Method of Placing and Tamping.

When a concrete road is constructed on the continuous system, obviously the concrete should be deposited over the full width of the road at one time. If it is impossible to divert the traffic for this purpose, then the strip method of construction should be adopted.

The sides of the road, where there is no kerb, must be supported at the end of each day's work by a wooden or metal form sufficiently strong and properly braced to resist straining out of shape under the pressure of the concrete. All mortar and dirt must be removed from forms which have been previously used, and the forms greased or oiled before any concrete is deposited against them. The side forms should remain until the concrete is sufficiently hard to permit their removal without damage to the edges, usually not more than 24 hours. In removing the form at the end of the previous work (to resume operations the next day) special care must be taken to ensure that the concrete is not damaged, and in beginning the placing of concrete special care must be taken with the process of tamping to ensure that the previous day's work is not disturbed or damaged in any way. When placing the concrete special care must be taken to ensure that this is well "sliced" against the forms. When expansion joints filled with a joint-filler are used they are provided at intervals of 50 or 60 ft., and an additional joint may be put in at the end of the day's work. These joints should not exceed ½ in. in thickness, and the greatest care should be taken to produce uniformity in the level of the concrete on each side of the joint. This can best be done by using a short straight-edge, notched in the centre to pass over the joint filler.

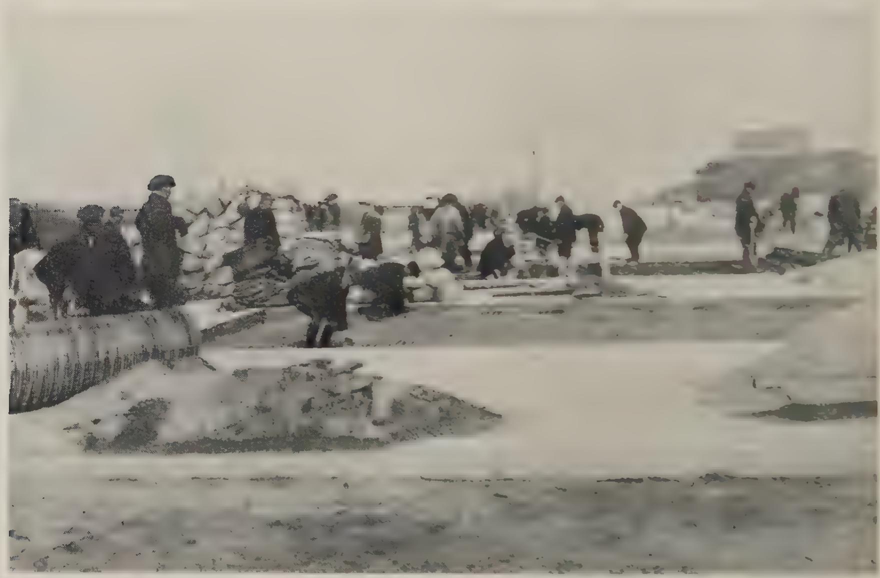

Fig. 491.—Marine Parade South (Concrete Extension), Great Yarmouth.

It is also important to tool the top edge of the concrete adjoining the filler to a radius of about ¼ in. The three stages in making a joint are shown

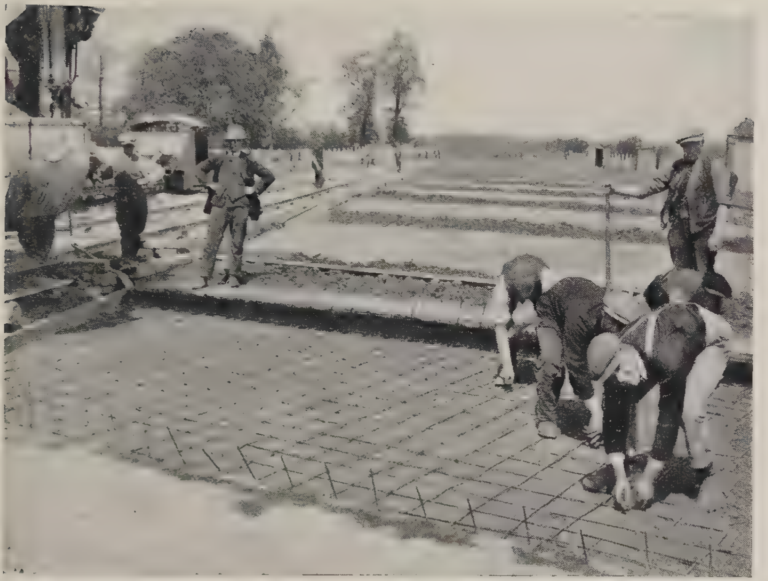

Fig. 492.—Alternate Bay Method, with Earth Curing.

in *Fig.* 494. The filler may protrude $\frac{1}{2}$ in. to $\frac{3}{4}$ in. above the surface of the road, in which case it should be flattened down with a hot iron before the traffic is put on. The alternative is to use a steel plate, well oiled on both faces, and fill with a bituminous compound on removal. It is advisable to

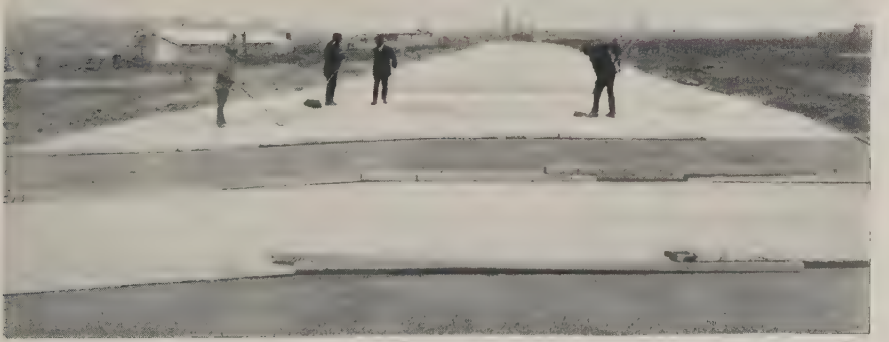

Fig. 493.—South Denes Road : Showing Alternate Bay Construction.

introduce expansion joints in places exposed to extremes of temperature, and also alongside the kerb or channelling, when the concrete road is not already carrying the kerbing.

Where no expansion joints are provided the concrete should be finished off at the end of a day's work with a vertical face by ramming the concrete against a smooth timber plank. This timber form should be kept true to line and vertical, and every care exercised to obtain a smooth face to the concrete when the plank is removed.

Longitudinal joints may be tongued and grooved in order to distribute the loads better over the two panels, but if adopted allowance must be made at the side of the road to allow the concrete to move transversely as well as longitudinally.

When the concrete is laid in half widths the vertical face of the concrete in the centre of the road should be treated as in the case of transverse joints; instead of bitumen, oil may be used on the vertical face of the concrete first laid and the second half width will then butt against this oiled face. All voids in the face should be filled up before the oil is applied to prevent any adhesion with the adjacent slab.

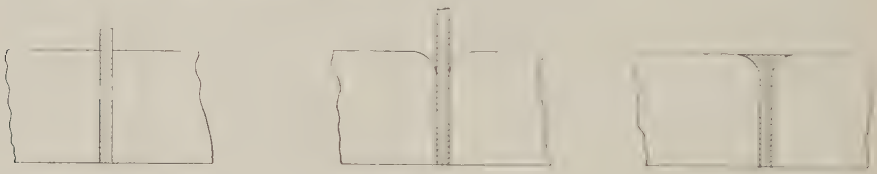

Fig. 494.

Under average conditions a total thickness of about 7 in. will probably be sufficient. The surface course of two-course roads should be approximately 1½-in. thick. When a two-course road is being laid the upper course or wearing surface must be spread on the lower course immediately after the latter is deposited and before it has begun to set.

Immediately after being placed in position the concrete must be struck off to approximate grade and camber and then thoroughly consolidated to eliminate all voids and surface moisture. This consolidation is effected by tamping the surface of the concrete, either mechanically or by hand, or it may be done by rolling. In no event should any tamping device be used which tends to cut below the concrete surface, as this only brings the cement to the surface; in other words, the tamper should not be less than 2 to 3 in. wide. A design for a hand-tamper is illustrated in *Fig.* 496. The finished surface should have a cross fall sufficient only to ensure that the surface water will pass off the roadway quickly, and should not vary more than ¼ in. from true shape. It will be found that, at the most, a cross fall of 1 in 40 will be sufficient. Various tools used in concrete road construction are illustrated in *Figs.* 495 to 498.

In cool weather no cessation of work of more than half an hour's duration should be permitted, except at the end of a completed bay. In hot weather the work must, if possible, be continuous.

The concrete may be reinforced with steel reinforcement at the discretion of the surveyor. Reinforcement appears to be essential on bad ground. The correct amount of top or bottom reinforcement has not yet been generally agreed. On a road constructed on the continuous principle it would appear to have its advantages in the middle third when the thickness of concrete is uniform throughout the section. The same applies to alternate bay construction when the bays are more than 15 ft. wide. On the other hand, in the case of strip construction the only possible place where steel reinforcement may prove of advantage is at the sides, and especially at the corners.

Curing.—The concrete should be sprayed with water as soon as it has sufficiently hardened to withstand pitting, and be kept wet until covered, within 24 hours, with clay, earth, or other material, which must be kept thoroughly wetted for a period of at least 10 days. When sunshine, a drying wind, or other conditions make it desirable, the freshly laid concrete should be protected by canvas or other covering laid on the concrete surface until set sufficiently to be watered and protected as prescribed.

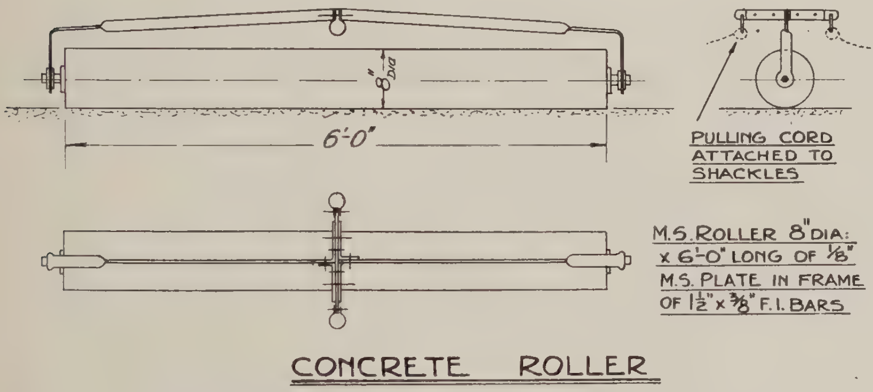
8" DIA
6'-0"
PULLING CORD ATTACHED TO SHACKLES
M.S. ROLLER 8" DIA: x 6'-0" LONG OF ⅛" M.S. PLATE IN FRAME OF 1½" x ⅜" F.I. BARS
CONCRETE ROLLER

Fig. 495.

The road should not be opened to traffic until at least 21 days after it is laid, and when the weather is cool or wet this period should be increased. Where the road is constructed in half-widths the traffic should not be concentrated on the first half which has been concreted until at least one month after completion, or longer where weather conditions make it desirable. If rapid-hardening Portland cement is used, the road may be opened to traffic from 4 to 9 days after it has been laid according to the time of year.

If a tamping screed is used on bad ground, great care must be taken that the side forms are set firm, and particular attention paid that there are pegs close to the joints supporting the forms.

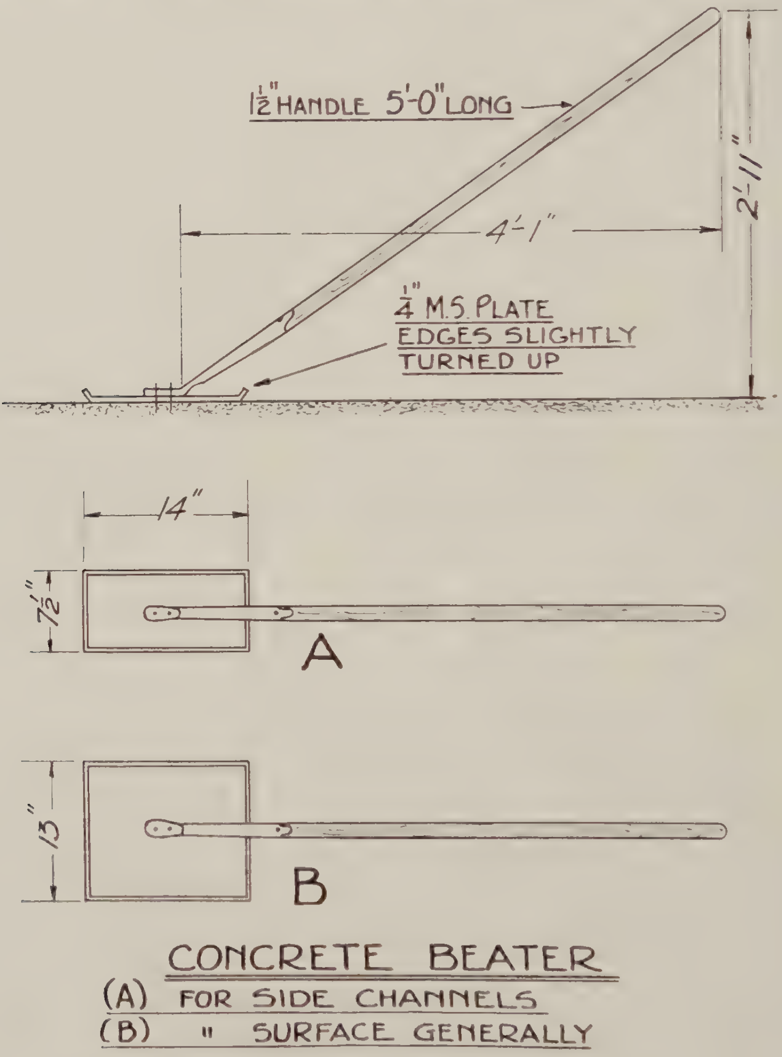
1½" HANDLE 5'-0" LONG
2'-11"
4'-1"
¼" M.S. PLATE EDGES SLIGHTLY TURNED UP
14"
7½"
A
13"
B
CONCRETE BEATER
(A) FOR SIDE CHANNELS
(B) " SURFACE GENERALLY

Fig. 496.

The drains to gulleys across the road should be laid well ahead, preferably just off the road, and ballast filled on top. It is advisable to place an extra layer of reinforcement at 2 in. from the top of the concrete extending about

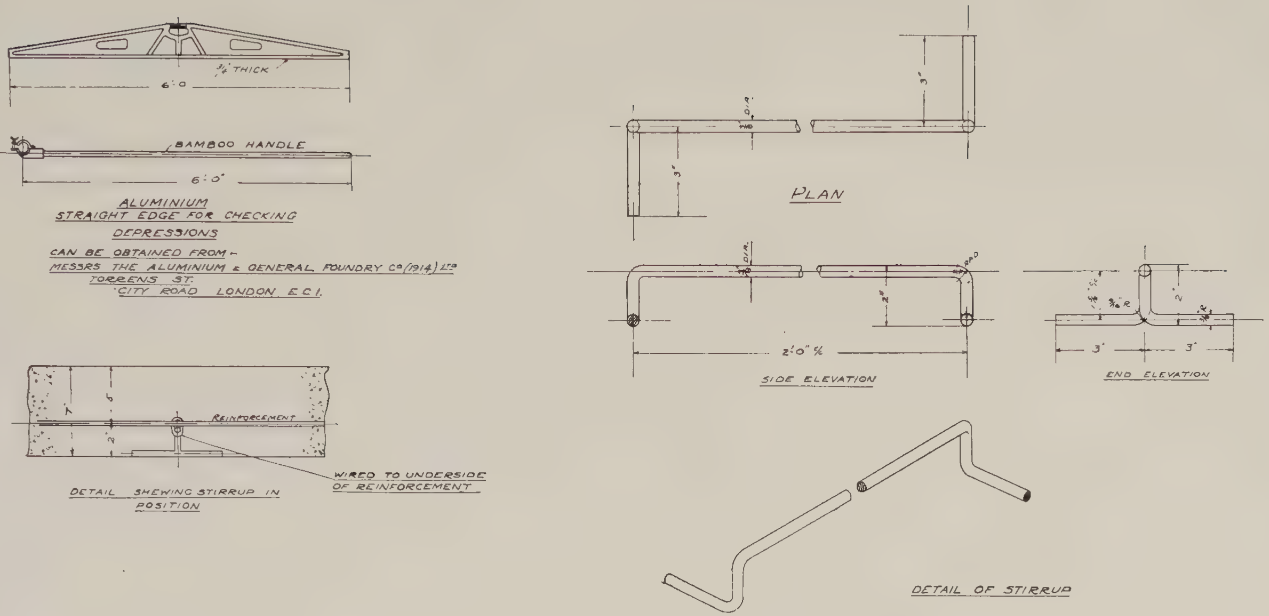
3/4" THICK
6' 0
BAMBOO HANDLE
6' 0"
ALUMINIUM
STRAIGHT EDGE FOR CHECKING
DEPRESSIONS
CAN BE OBTAINED FROM –
MESSRS THE ALUMINIUM & GENERAL FOUNDRY Co (1914) Ltd
TORRENS ST.
CITY ROAD LONDON E.C.1.
REINFORCEMENT
WIRED TO UNDERSIDE
OF REINFORCEMENT
DETAIL SHEWING STIRRUP IN
POSITION
DIA.
3"
3"
PLAN
DIA.
2"
2' 0" %
SIDE ELEVATION
2"
3/16" R
3"
3"
END ELEVATION
DETAIL OF STIRRUP

Fig. 497.—Tools for Use in Concrete Road Construction.

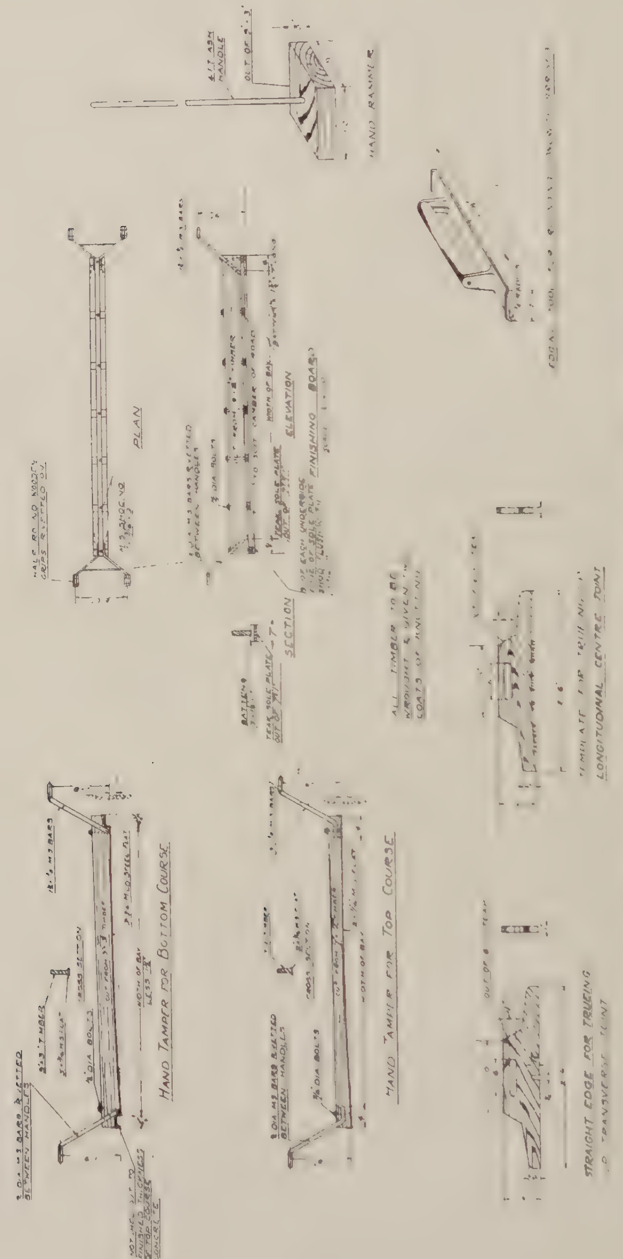
HAND TAMPER FOR BOTTOM COURSE
HAND TAMPER FOR TOP COURSE
CROSS SECTION
PLAN
ELEVATION
SECTION
FINISHING BOARD
HAND RAMMER
ALL TIMBER TO BE WROUGHT & GIVEN
STRAIGHT EDGE FOR TRUEING
TRANSVERSE JOINT
LONGITUDINAL CENTRE JOINT

Fig. 498.—Tools for Use in Concrete Road Construction.

1 ft. or 1 ft. 6 in. over each side of the trench. When the road is constructed in wider strips than 15 ft. it appears advisable to use top reinforcement in the middle third of the bay or alternatively thicken the concrete in the centre.

Crossings must be left for future house drains, gas mains, cables, etc. These can be filled in temporarily with a row of granite setts, hard-core, or concrete, which will also act as breathers during initial setting. The scum pushed to the end of the previous day's work should be cut away to a depth of about 1 in. vertically through a length of at least 4 in. before starting the next day's work ; this should be done the next day, even if the work has to be left several days, as it is much more expensive later if the concrete is as good as it should be. This can be avoided, however, if the last 3 ft. below any joint are tamped away from instead of towards the joint.

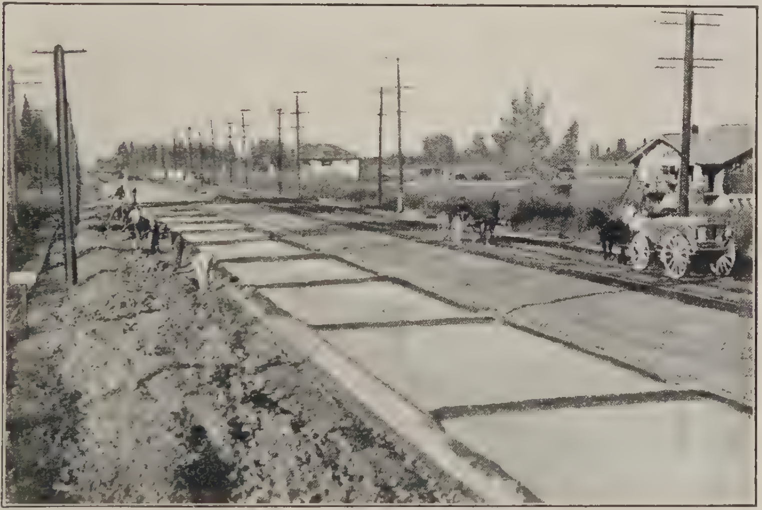

Fig. 499.—Curing by "Ponding."

Maximum and minimum temperatures should be taken each day, and it should be remembered that the British Standard tests are generally at about 60 deg. F., whereas the work may be taking place at a temperature of 36 deg. or 80 deg., and that the setting-time is lengthened or shortened according to whether the temperature be low or high. In hot weather the work should not be stopped for meals. Gangs should be halved through the dinner-hour, and if a two-course road is under construction the upper course must be placed on the lower as quickly as possible ; the finishing board or belt must also follow very close. It is absolutely essential to keep the concrete moist during its initial set, and everything possible should be done to delay the set ; if it is allowed to set quickly cracks are bound to appear. The midday sun is a very difficult problem, and must be guarded against.

In cool weather half an hour for dinner may be taken by the whole gang, and the top course need not follow quite so closely. A covering of sand or earth is very desirable, as it retains the moisture from rain and only needs occasional watering. On removing the covering the road will look patchy, but that appearance is given by the cement slurry, which traffic quickly removes ; granite chippings do not adhere to it, nor is it in any way disturbed by the use of this material. Next day the covering should be removed and the concrete covered with sand or earth and saturated with water.

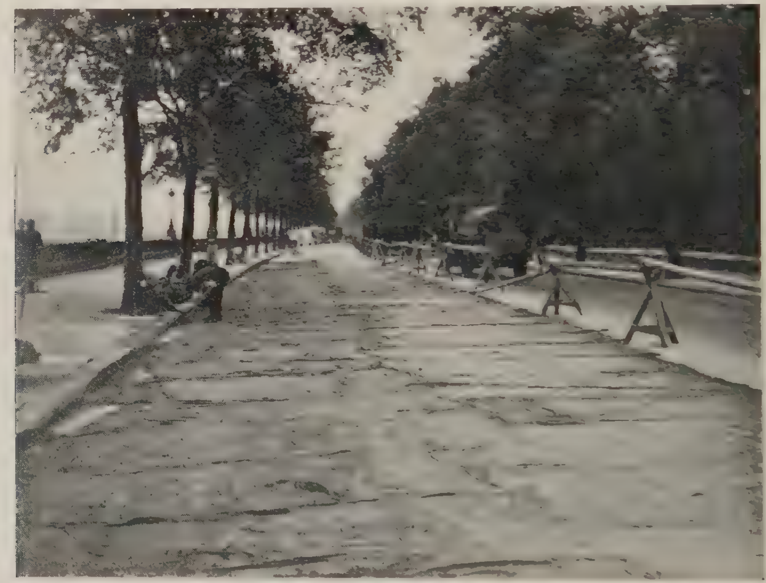

Fig. 500.—Curing with Damp Canvas.

In winter, good covering is still essential, but watering must not be done if frosts are prevalent.

In a two-course road both courses should be tamped. The granite chippings must be sharp, very clean, and free from dust. The ballast aggregate for the bottom course must be properly graded and very clean—much cleaner than many so-called "washed" ballasts as supplied. In summer the cement must be slow setting, but may be rather quicker in winter in order that the initial set may take place before the night frost appears.

A wood float should not be used *ad lib.*, as it is liable to undo all the good work already done, unless it is used in a very skilled manner and before the set has taken place. No steel float should be used.

The mix must be a little wetter in summer than in winter, but never sloppy, and never so wet as men unaccustomed to concrete road work like it. The wetter it is the easier it is to work up a surface, and less tamping has to be done per square yard. On the other hand, the surface must not be tamped to such an extent that an excess of cement will be brought to the surface; for this reason the finishing board has many advantages, and the tamping of the top course may be considerably reduced if the finishing board is used on concrete of a medium consistency.

In cases where concrete roads are to be built on marshy ground, the actual roadway should be of light construction, and it is essential to have the reinforcement at the bottom to resist the reverse bending moment; reinforcement is also sometimes put near the top to resist contraflecture.

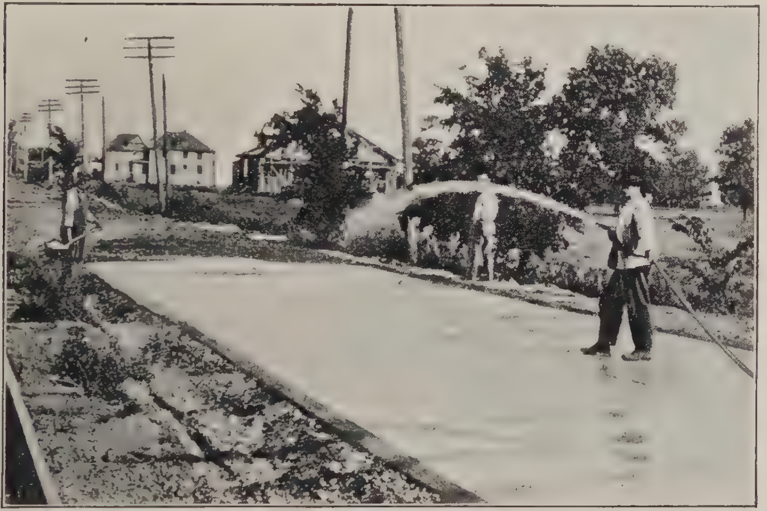

Fig. 501.

Ditches should be filled in with hard-core, ashes, or dirty ballast to a depth of about 2 ft. and rolled with a six-ton roller, or a heavier roller if the surrounding surface will stand it. The object is to get the same strength of surface all over; it is not necessary to make the ditch fill stronger than the natural ground. At least 3 in. of ashes should be spread all over the bed and rolled in. Rolling in wet weather should be avoided, as the ashes get rolled into the alluvial deposit or mud and are wasted. In addition, the ashes make a clean base for the men to work on. The ashes must be thoroughly burned, as it cannot be guaranteed that none of them will get into the concrete during the construction of the road—if unburnt ashes escape into the concrete, " blow holes " will occur. When concreting, the layer of ashes must be sufficiently damp to prevent moisture being absorbed from the bottom concrete layer, as should this take place it may be assumed that the bottom inch of concrete is of no value from the strength point of view.

The fine aggregate or sand should not include an excessive proportion of fine particles, and preferably should be graded from ⅛ in. downwards, but not more than 20 per cent. by weight should pass a 50 × 50 sieve. If only fine sand is available, a greater proportion of cement must be used, as every particle of sand must have its coating of cement to ensure a good concrete, and many engineers in these circumstances first mix the sand and cement dry, and then add the coarse aggregate in order to obtain the desired result.

Most sea-shore gravels are suitable when screened to their proper sizes. Pit-ballast generally requires washing, and is then usually suitable. Limestone is not perfect as a top-course aggregate, as it wears into a rather slippery surface, but it is excellent for the bottom course. Whinstone makes good concrete; the "flour," however, should not be used, and as the chippings are apt to crush rather flat, care should be taken, in the case of a two-course road, to obtain them from a quarry which produces a very large proportion of cubical chippings. Granite is good for either one-course or two-course roads, both as coarse aggregate or as chippings, which are generally cubical. Some slags make a very good concrete, but care should be taken in selection; if sulphur is present the slag should be discarded unless the percentage of sulphur is almost negligible.

Sea sand is generally satisfactory, but blown sand, if used, must be carefully tested with cement first, as it will generally be found that a large quantity of the latter is required to make anything like a satisfactory concrete. Clinker obtained from a destructor, if carefully selected, makes a suitable aggregate, but should be tested chemically.

The first essentials in obtaining a wear-resisting surface to a concrete road are good materials and good workmanship, but the surface of concrete may be hardened by applying to it a solution of sodium silicate as soon as the concrete has sufficiently dried out. This material acts by converting the hydrate of lime that is liberated during the setting of cement into silicate of lime, which has the property of hardening. The concrete is only hardened to the extent to which the sodium silicate solution penetrates. Sodium silicate is not a proprietary article, and can be obtained in bulk from any manufacturing chemists. There are, however, several forms, and for hardening concrete the most useful form is that known in the trade as the "3·3 ratio," which means there are 3·3 molecules of silica present per molecule of soda. This material is generally sold in the form of a concentrated solution, and for application to concrete one gallon of the solution should be mixed with five gallons of water. A convenient way of applying the solution is to brush it over the concrete, and no more should be put on the concrete at any one time than can be absorbed. Three applications at intervals of twenty-four hours are desirable. Many of the concrete roads in the London boroughs, and elsewhere, have been successfully treated in this manner.

CEMENT-BOUND ROADS

In recent years the need for a road which will be stronger and more durable than ordinary water-bound macadam roads but not so costly to construct as an all-concrete road has led to the development of the cement-bound road. This type of road has been successfully tried out in the United States and elsewhere, and is being increasingly developed in Great Britain.

The most serious disadvantage of the waterbound road is that it has not strength to resist internal attrition, and by reason of the presence of water the road materials undergo severe stresses during winter. When frosts occur the water between the stones of a water-bound macadam road expands, and as soon as a thaw comes cracks are left between the stones. This effect is particularly noticeable when the stone is of a pervious nature.

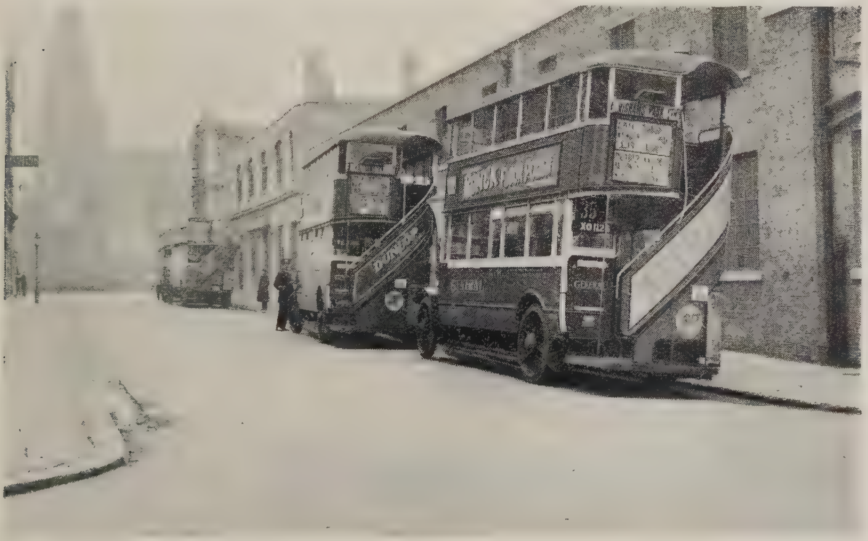

Fig. 502.—Venn Street, Clapham: A Cement-bound Road.

Tar spraying will protect the surface and defer its disintegration, but the effect of spraying can only be of a temporary nature, and does not provide strength in the body of the crust to resist internal attrition. It cannot prevent the water already there from freezing, expanding and causing cracks. It has been found that the breaking up of a macadam road is due 10 per cent. to traffic, 5 per cent. to weather, and 85 per cent. to internal attrition.

On secondary roads with reasonably good foundations and carrying moderate traffic, a process for binding the new surface right through, at a reasonable cost, has been evolved and developed. The object is to coat each individual stone, not only in the surface but through the slab, with cement mortar, and to bind them together with the aid of a roller. The mortar takes the place of hoggin and provides the strength to meet the disintegrating effect caused by internal attrition. A sample of cement-bound surfacing, approximately 120 sq. ins. by 4 ins. thick, taken from a main road in Co. Louth and crushed to destruction, broke under compression at 170 tons, equivalent to 3,160 lbs. per sq. in. The mix of sand and cement was 2 : 1.

Cement-bound roads were laid in America and France before the system was tried in Great Britain and Ireland. An inspection of American roads in 1926 showed that roads laid from five to seven years were still standing up well to moderate traffic, with no indication of disintegration of the slab.

A length of about two miles of cement-bound road was laid in the spring of 1926 on the main trunk road between Dundalk and Newry, Co. Louth, carrying 1,500 tons of traffic a day ; this has since been increased by bus traffic. A 2 : 1 mortar was used and the surface so well bound that it is now possible to crack the stones (of a hard porphyritic nature) in the surface without breaking the bond of the mortar around them. Inspection eighteen months after the road was constructed disclosed no sign of wear, breaking up of the surface, or any indication of pot-holing, and the present condition of the road indicates that a life of several years may be expected ; no maintenance has been required.

A further example of the value of a rich mix providing a strong wearing coat with an impervious surface is at Wakefield. Here several sections of this type of road have been constructed on gradients, a 1 to 1 mix of mortar being used. The first two sections were laid in 1925, and are still giving satisfactory service. A section of cement-bound road laid early in 1927 on a 6-in. concrete foundation on High Road, Balham, carrying 32,000 tons a day, shows no sign of disintegration.

When first open to traffic a cement-bound road is inclined to be dusty until the surface slurry has been cleaned off by the traffic. If necessary this dusting can be arrested by an application of silicate of soda. Once the surface has been cleaned, and the stone is taking the wear, a non-slippery level surface is provided. Such an impervious surface, assuming no hollows are left in it, will not hold water and the effect of frost is minimised, and as there is nothing of an oily nature in the materials used to construct the road the risks of slipping or skidding are slight. At Ashbourne, Derbyshire, a cement-bound road was laid on Buxton Hill, a gradient of 1 in 7. The surface provided gives ample evidence of the non-slippery properties of the cement-bound road.

In this type of construction, the use of a concrete mixer is advisable.

The speed of the work is controlled to a great extent by the size of the mixer, and this should not be too small. Beyond timber for side forms and tampers no further plant is needed other than that used in water-bound work.

Where a strong mortar has been used and an impervious surface obtained, frost and rain have little, if any, effect on the road. Except during frosty weather, when work should cease, cement-bound roads may be laid as long as the men on the job can work. Showery or damp weather helps in the curing of the road.

In England the cost of a cement-bound road varies from 3*s*. 4*d*. to 4*s*. 6*d*. a yard super, for an average thickness of 3½ ins., while in Ireland the cost of the finished road has varied from 2*s*. 4*d*. to 3*s*. 6*d*. per super yard, dependent on the prices for materials and labour. These prices are for surfacing alone and do not include the laying of a foundation.

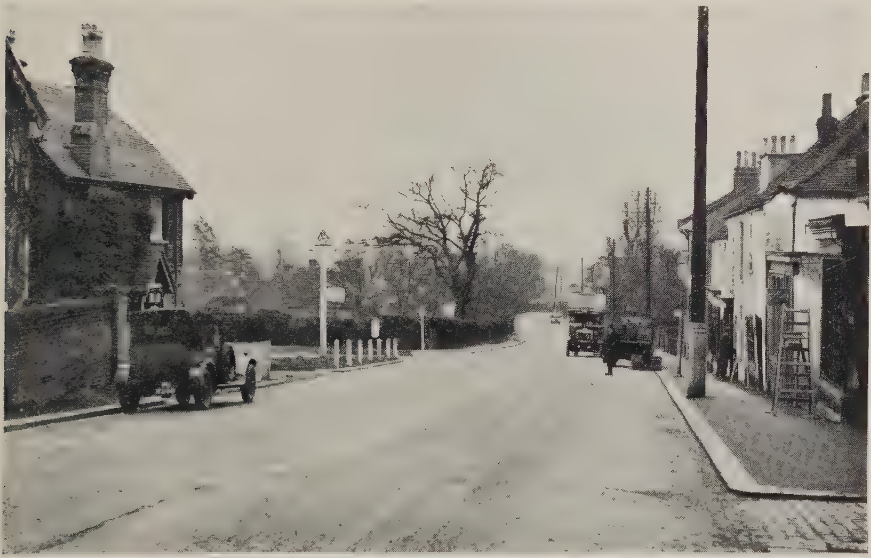

Fig. 503.—Stanmore Hill: A Cement-bound Road with a Gradient of 1 in 12.

Construction.—The method adopted for several roads, one of which was the stretch of 2 miles in Co. Louth, is as follows: The work was done in half-widths. Timber balks 4 in. by 4 in. were spiked down the centre of the road and the stone, graded from 1½ in. to 2½ in., spread to the full thickness. While spreading operations were proceeding the sand and cement were mixed in the proportions of 3 : 1 dry. The dry binder was then spread evenly over the loose stones and, where any of the latter were damp, they were shaken up with forks. From 60 to 80 super yards were covered in this manner and the roller run over the section once or twice to press the dry binder down. At the same time any raw patches were filled with a further application of binder. A man with a hose then went over the treated surface with as even an application of water as possible and, by removing a stone here and there for inspection, ensured that the binder was well dampened right through.

The roller was again put on and the surface rolled to consolidation, the top stones showing up at this stage. While rolling was proceeding a 2 : 1 mortar was mixed wet and then spread evenly over the surface. All surface voids were filled and the roller again put on to work in this sealing coat. After the roller had been removed surplus slurry was brushed forward into the next section to be laid. A large application of water will considerably reduce the strength of mortar in the sealing coat ; but a certain amount of water must be applied to the wheels of the roller to prevent the picking up of mortar and stones. These difficulties in construction were overcome in Louth and other places, but led to another method being tried and adopted on a larger scale.

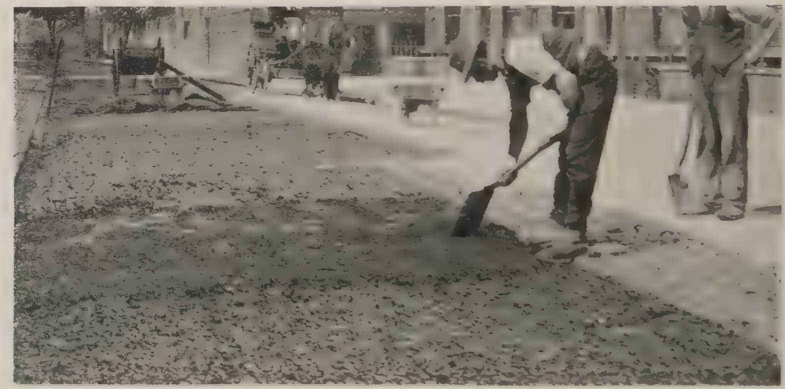

Fig. 504.—Cement-bound Roads : Spreading Mortar on Bottom Layer of Stone.

This process, known as the " Sandwich " method, is simpler in construction and there are indications that even better results will be obtained than by the dry method. The first cement-bound road to be constructed on the " sandwich " method in this country was at Cooling, Kent, the work being carried out by the Hoo R.D.C. This proved satisfactory and was followed by a section at Stevenage, where several new features were introduced into the construction. Other sections were then laid at Reading, Epsom, and in Ireland.

First it must be pre-supposed that an average sound foundation is obtainable. Should the old surface be full of potholes the road may be either scarified and rolled well, or the potholes filled with 12 to 1 concrete or with rubble or coarse material and then well rolled. It is of importance that the sub-base be firm and hard, otherwise the binder will percolate into it and it will be found difficult or even impossible to bring it up to the surface when rolling. Where an old tar-sprayed surface exists it is preferable not to disturb it, but to allow the concrete slab freedom of movement when expansion or contraction takes place.

The materials used are broken stone, broken granite, basalt or other approved stone, cubical in shape and broken to the B.S.S. for 2 in. broken stone, and free from flakes; sand (clean, evenly graded from $\frac{1}{8}$ in. to fine), and Portland cement. Good-wearing stone should be used if at all possible.

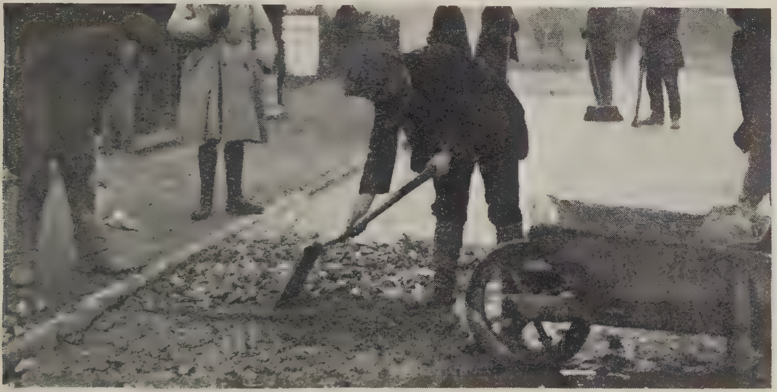

Fig. 505.—Cement-bound Roads: Spreading Second Layer of Stone.

Apart from the bad wearing qualities of a soft stone it is liable to be crushed or cracked under the roller. Such a stone will not last and will be drawn out and leave a small hole in the surface. Many stones of this type produce a bad surface and the only remedy is to spray periodically. On the other hand, a good wearing stone which will not crush under the roller will require no spraying over a term of years, and the extra cost of even 1*s.* per super yard of road for a better stone may be amply repaid.

Should work be done in half-widths, strong well-seasoned timber, say 4 in. by 4 in., should be securely spiked down the centre of the road so that it will not arc or turn over under the weight of the roller. Timber should be laid at the correct level and distance on the haunch where no kerb or strong verge exists. Should no verge exist, it is advisable to strengthen the road with rolled-in concrete (say 10 : 1) or by putting in a kerb.

The formation having been prepared and timbers laid, broken stone is spread about half the required thickness of loose stone. Should the stone be dry or dusty it should be given a light watering, since a dry stone will absorb moisture from the mortar and so prevent it flushing to the surface under the action of the roller. The bottom layer of stone is then laid and given a light rolling to level it, care being taken that not more than one or two runs with the roller are given, otherwise the stone becomes too consolidated and so prevents penetration by the mortar binder. During the above operation the mortar "sandwich" or binder may be mixed; this should be composed of 2 parts to 1 part cement and should have enough water to render it thoroughly plastic and about the consistency of that used for pointing work.

While spreading, care must be taken to slice the mortar down the sides of the timber and side forms by means of a shovel. As the mortar is spread the top layer of stone is then spread over and levelled by rolling, and this must also be given a light watering if the stone is dry or dusty.

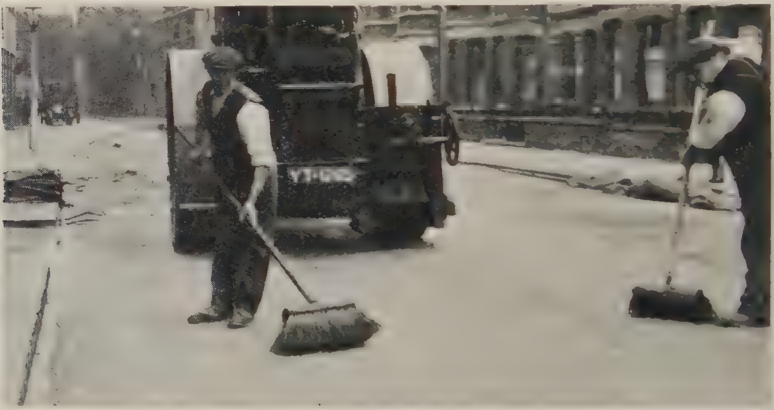

Fig. 506.—Cement-bound Roads: Consolidating by Rolling.

During summer months 1¾ hours are allowed to finish off a section, estimated from the time of mixing the first batch of mortar; this period can be increased to 2 hours in winter. The spreading of stone and mortar can therefore continue for an hour, when a sufficiently large area should have been laid for the roller to work over. It is obvious that this is dependent on the output of mortar, assuming that the stone is deposited in loads on the site and easily spread. Experience has shown that a 10–7 cubic foot mixer will produce sufficient mortar to allow the roller to complete a reasonable section within the time limit. With a gang of 16 men, sufficient output can be provided to keep the roller working and so avoid the necessity of making a series of joints through the day's work. In continuous work care must be taken that the roller does not work over any section in process of setting.

The effect of the roller on this sandwich of stone, mortar, and stone is to squeeze the mortar down and up. After 10 minutes or so of rolling the mortar should begin to show on the surface, and when this occurs the surface should be given a soft brushing. Rolling will then continue until the slurry has worked up and all raw patches have closed up. Should a heavy roller be used, it may be difficult to remove all trace of wheel marks. Rather than over-roll and run the risk of crushing the surface stones, it has been found better to beat out the wheel tracks by means of a finishing board of say 2 pieces of timber 9 in. by 3 in., bolted together and sufficiently long to work over the side forms. The board, shaped to the required camber, is also useful (if the side timbers are correctly laid) for showing up any slacks left in the surface. A light hand roller pulled longitudinally has also given good results in procuring a good finish and eradicating the slight waviness left by a heavy steam roller.

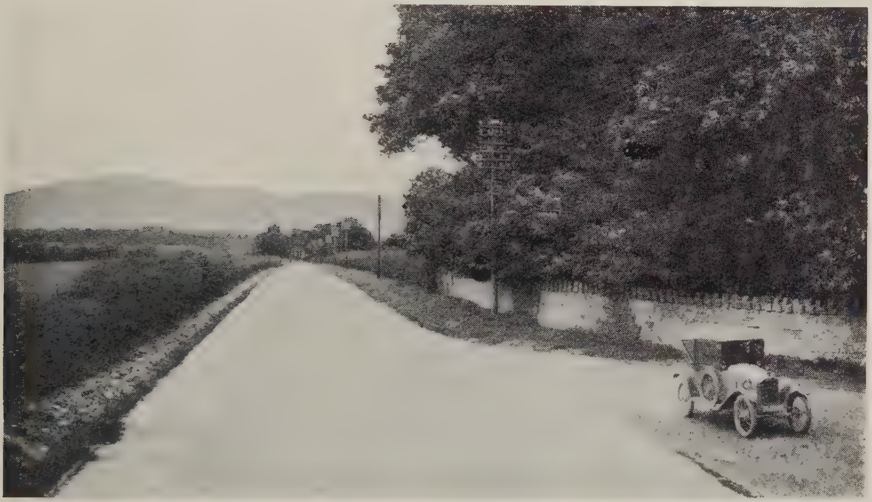

Fig. 507.—Cement-bound Road in County Louth, Ireland.

To finish off the day's work a timber balk should be spiked transversely and the roller worked over it. The following day it can be lifted and there should be a clean level consolidated face to work to. Work will then begin in the same manner, the stone being spread up to the joint and the mortar deposited well into it. The roller must not run over the previous day's work, but only up to the joint. The joint must be carefully levelled by ramming with a square wooden tamper.

Should a heavy shower occur whilst work is proceeding, thus removing the mortar from the surface, the water lying on it may be drawn off with a soft broom and a dusting of dry mortar spread over and worked in with brushes.

Where a road can be closed to traffic and the whole width laid in one operation, on a narrow road, say 15 ft. wide, it would be possible to carry out the work continuously with a joint at the end of the day's work. Where a wider road of, say, 24 ft. to 30 ft., is under construction, means must be provided for producing a sufficiently large quantity of mortar and stone, and there must also be a large gang to place and roll it. In such a case it is advisable to prepare for a joint at midday and to spread the macadam for a certain length right across the road, timbers being laid and spiked as described.

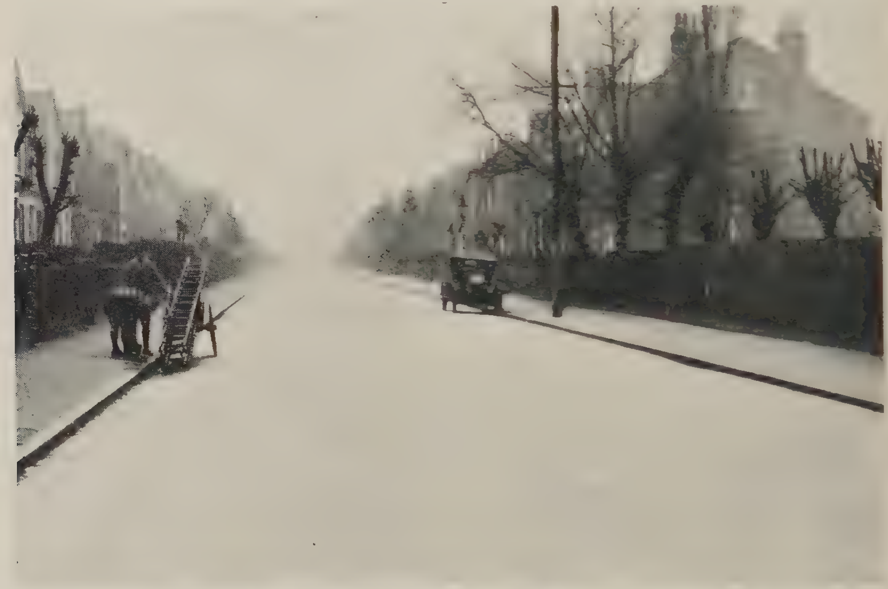

Fig. 508.—Eardley Road, Wandsworth: A Cement-bound Road.

Assuming the road is 30 ft. wide, the procedure is as follows:—The lower-course macadam is spread for a length of, say, 10 yds. and a width of 4 yds. This operation should take about an hour, and will give a section sufficiently long and wide for the roller to work on. Rolling should be started near the channel, working towards the centre. Meanwhile the process of spreading mortar and surface stone continues, this latter being done in strips 3 ft. or 4 ft. wide, by the full length of 10 yards, right across the road. The roller should then work slowly across, following the spreading, care being taken that it has been consolidated, shaped, and finished flush with the first section before the time limit has elapsed. It is advisable to lay timber screeds on the haunches where no kerbs exist. After mid-day work proceeds on the same lines as during the morning, the roller working up to but not across the joint, which must be levelled and made good by hand.

Where " Ferrocrete " Portland cement is used curing can be done by placing canvas on the surface and keeping it damp, and after a period of 48 hours passing a water cart over the road two or three times a day for a week or 10 days, dependent on the weather. In very cold or frosty weather it is advisable to cease work, as the cement content is comparatively low, thus making it more easily attacked by frost. A rapid-hardening Portland cement is recommended since the strength obtained in a short period will enable a road to be opened from 4 to 5 days in summer and 7 to 10 days in winter, dependent on weather conditions. If ordinary Portland cement is used, traffic should be kept off the road for a period of from 3 to 4 weeks, dependent on time of year and traffic carried.

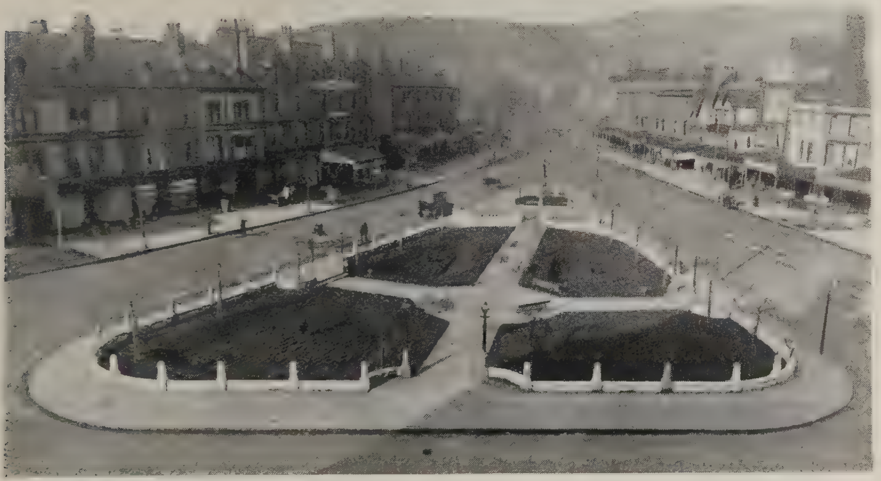

Fig. 509.—Concrete Garden Lay-out at Llandudno.

Successful experiments have been carried out where traffic has been heavy, such as at Balham High Road. Here the cement-bound surface 3 in. deep has been laid on a concrete foundation of 6 in. of reinforced concrete. This work was done in January, 1927, and indicates the high strength obtained by the grouting and the durability of the surface.

This type of road requires more camber than a concrete surfaced road. It should not be flatter than 1 in 36, since it is not as self-cleansing as the latter. It is not claimed that a cement-bound road will provide its own

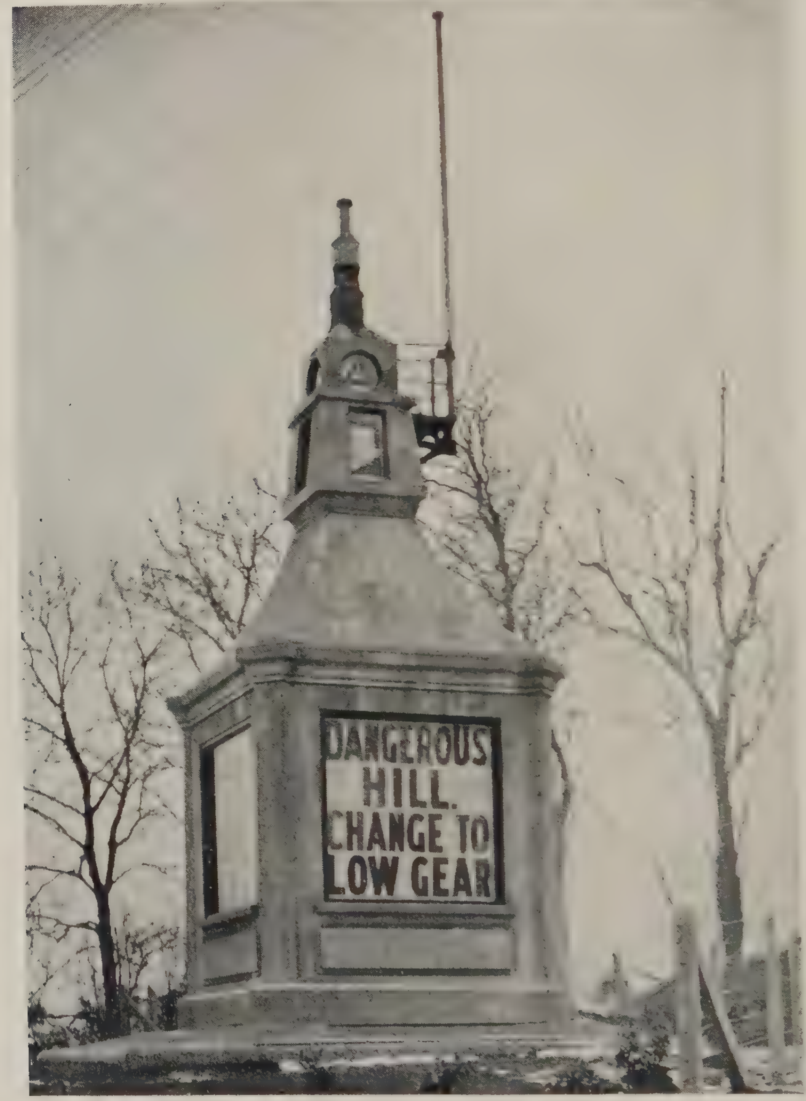
DANGEROUS
HILL.
CHANGE TO
LOW GEAR

Fig. 510.—Concrete Road Lighthouse at Congleton.

foundation and wearing surface under heavy traffic conditions, as is the case with a concrete road, but it will provide a surface which has the qualities of a concrete road in a high degree at a cost which is little more than that for waterbound work.

FOOTPATHS

The ideal footpath should be smooth without being slippery, impervious, wear-resisting and uniform in strength. Concrete is used in footpath construction either as pre-cast slabs (see Part VIII) or *in situ*. For either kind of path a stable, firm and well-drained foundation is necessary to prevent uneven settlement or cracks occurring. The latter are especially likely if water is allowed to seep under the path and frosts come. In well-drained soil the path may be laid on 3 or 4 inches of rolled clinker, ashes, or gravel, but on clay soils it is necessary to provide a sub-base of coarse clinker, broken stone or gravel to obtain drainage. This sub-soil should be rammed and rolled with a hand roller.

The concrete may be laid either in one or two courses using a 1 : 2 : 4 mixture of cement, sand and hard aggregate broken to pass through a $\frac{3}{4}$-in. ring. In one-course work the footpath is finished with a trowel as described under floor finishing (Part IV). In two-course work the first course is screeded off $\frac{1}{2}$ in. lower than the level of the finished path and the $\frac{1}{2}$-in. top course placed and floated off before the concrete below has set. This course should consist of one part cement to two parts of granite chippings.

In both methods the formwork required is alike, the kerb and a $1\frac{1}{2}$-in. board on edge parallel to the plinth of the railings in front of the houses providing two sides of the forms to each panel. In the longitudinal direction the path is divided into bays about 6 ft. in length by wooden strips $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick and the full depth of the concrete in width. Alternate bays are then concreted and allowed to harden, the edges along the tops of the strip being rounded off. The strips are then loosened and replaced in position. The remaining bays are then concreted, the wooden strips removed and the spaces left filled with sand or sand and tar.

In order to prevent the path being slippery it is advisable to roll the surface of the concrete with an indenting roller which produces marks giving a good foothold. The finished portions of the path should be screened from the direct rays of the sun while hardening.

Garden Paths

The construction of garden paths may be carried out on similar lines to those stated for one-course work. A thickness of $1\frac{1}{2}$ in. is ample when the foundation is good. In order to form the edges 1-in. boards set on edge and held in position by pegs must be laid in the direction of the path and at the required distance apart. The curved surface or camber of the path is obtained by a finishing board the under edge of which is cut to the required radius and which is worked along the tops of the side forms. The latter should project 1½ in. or 2 in. above the surface of the finished path at its edges (*Fig.* 511). If the surrounding earth is not to be level with the edges of the path it is advisable to round these off.

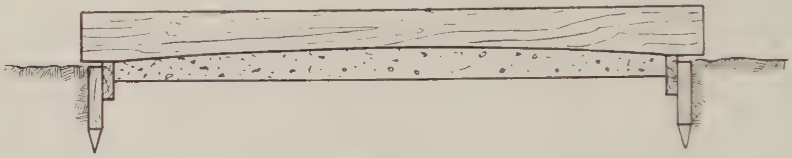

Fig. 511.

Crazy garden-paving is dealt with in Part VIII.

PART VI

HOUSES, COTTAGES, BUNGALOWS, GARAGES AND FARM BUILDINGS

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HOUSES, COTTAGES, BUNGALOWS, GARAGES AND FARM BUILDINGS

Although concrete houses were built more than fifty years ago, this type of construction is essentially a development dating from 1916 to 1918, when the scarcity of bricks made it essential to seek other materials for building large housing schemes, chiefly for the accommodation of munition workers at new industrial centres such as Gretna, Chepstow, and other districts. The success of many of these schemes from the points of view of economy and rapidity of erection, and the experience gained in their construction were of great value to the nation in the years immediately after the war, when the provision of a large number of new houses was a necessity of prime importance.

Concrete not only took its place with brick and stone as a proved material for house construction, but owing to the scarcity of skilled labour and the high cost of other materials concrete was at one time the only material in which houses could be built at reasonable cost. It was no doubt due to the competition of concrete that prices of houses built in other materials fell to nearly the same level as concrete houses, but in spite of the fact that the saving in cost is not so pronounced concrete is still used to a very large extent for housing schemes with every satisfaction, and in these days of big schemes it has to be remembered that a saving of £30 a house means a saving of £15,000 on an estate of 500 houses. Since 1918 many thousands of concrete houses have been built in Great Britain.

Most of the earlier houses were built of pre-cast concrete blocks, generally with cavity walls the two leaves of which were tied together with wall-ties. Various forms of hollow and tee-blocks were also used. More recently, however, monolithic, pier-and-panel, and other types of walling have been extensively introduced, and each method has produced satisfactory results. It has to be admitted that some of the earlier schemes did not prove entirely satisfactory, due generally to the prevalence of an idea that concreting was unskilled work and that no special knowledge was necessary in carrying it out. The result, as was to have been expected, was poor quality concrete that was not weatherproof or that cracked in an unsightly manner ; some of these houses showed, in fact, exactly the same defects as a "jerry-built" house in any other material.

But it is now thoroughly well realised that concrete house construction

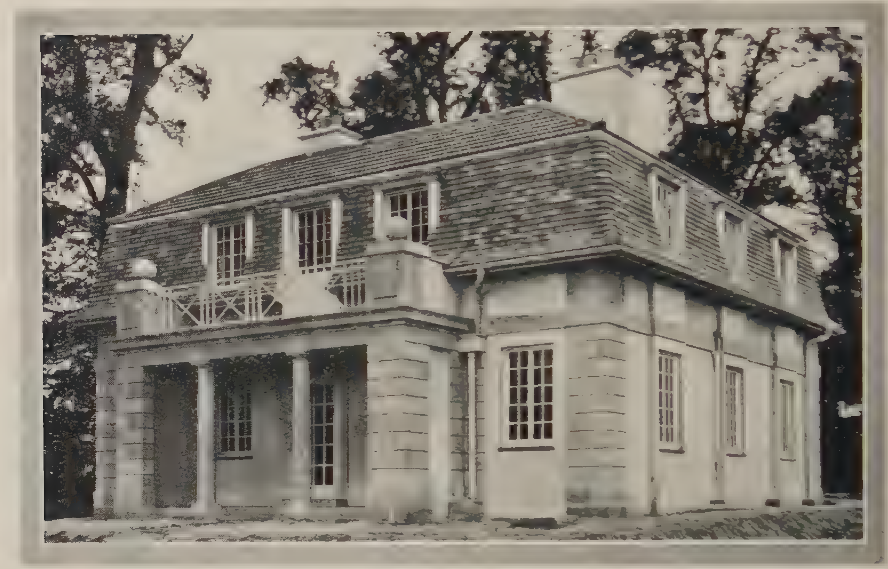


Fig. 512.—All-Concrete House.

needs skilled supervision, and that just as a bricklayer must know something about laying bricks, so the man in charge of labour on concrete housing work must understand his subject. The result of the appreciation of this factor is seen in the excellent concrete houses now being built all over the country.

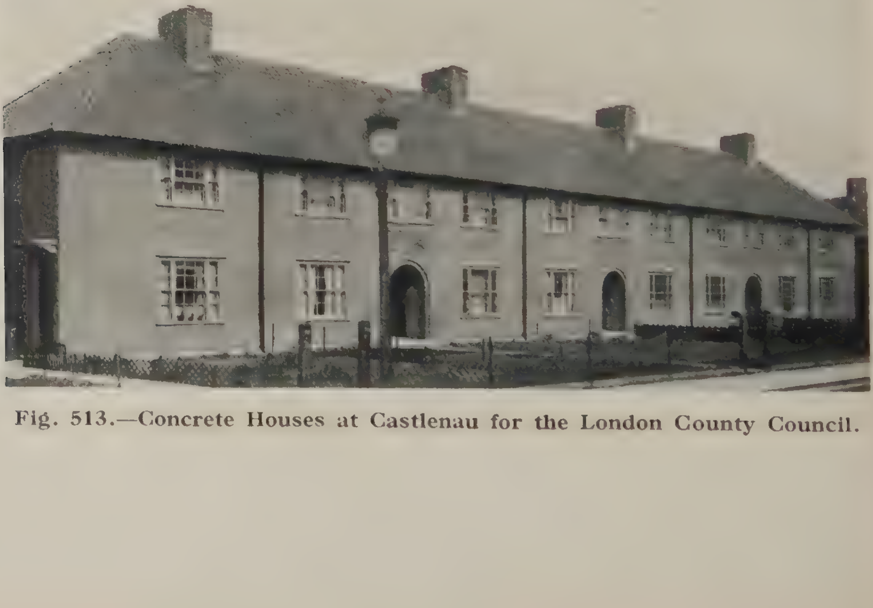


Fig. 513.—Concrete Houses at Castlenau for the London County Council.

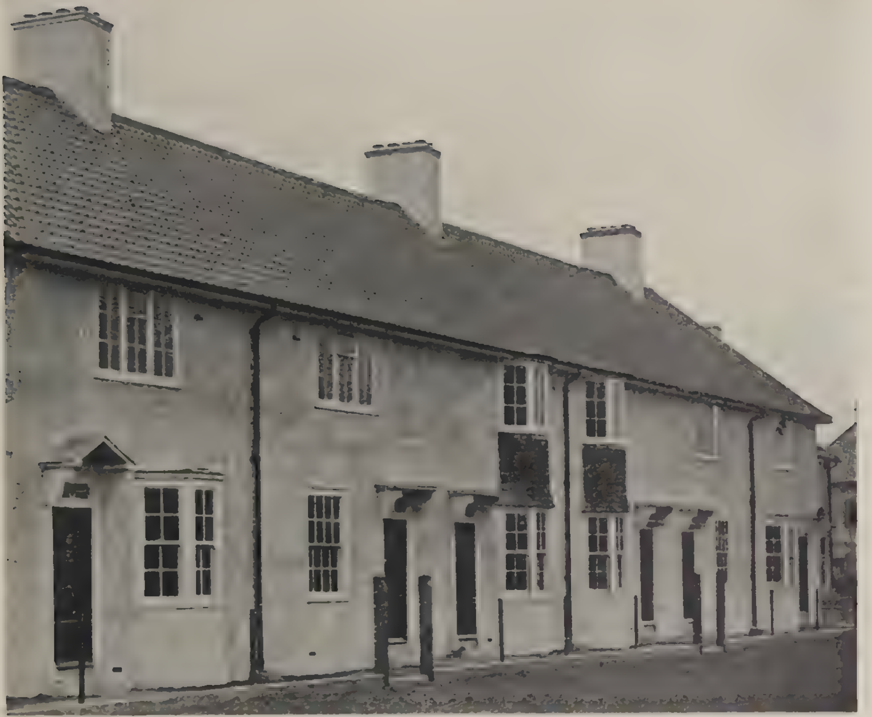


Fig. 514.—Concrete Houses at Tottenham for the London County Council.

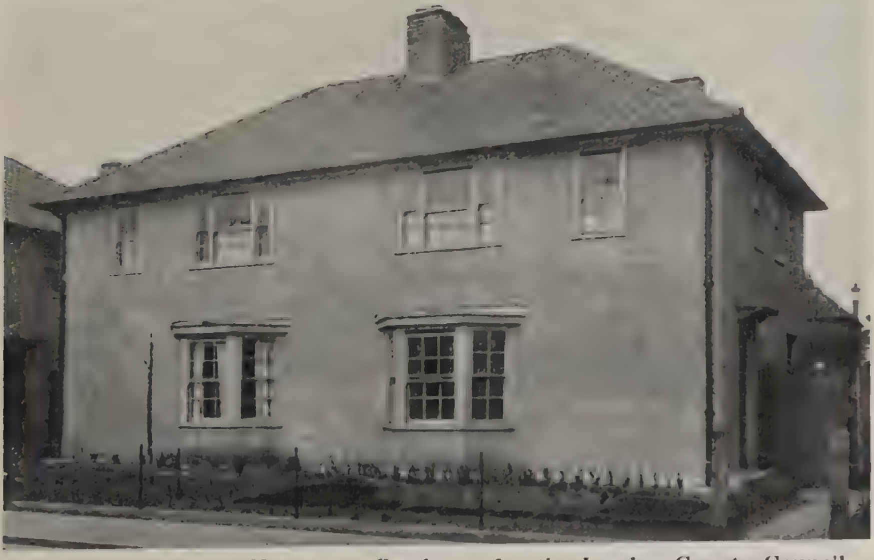
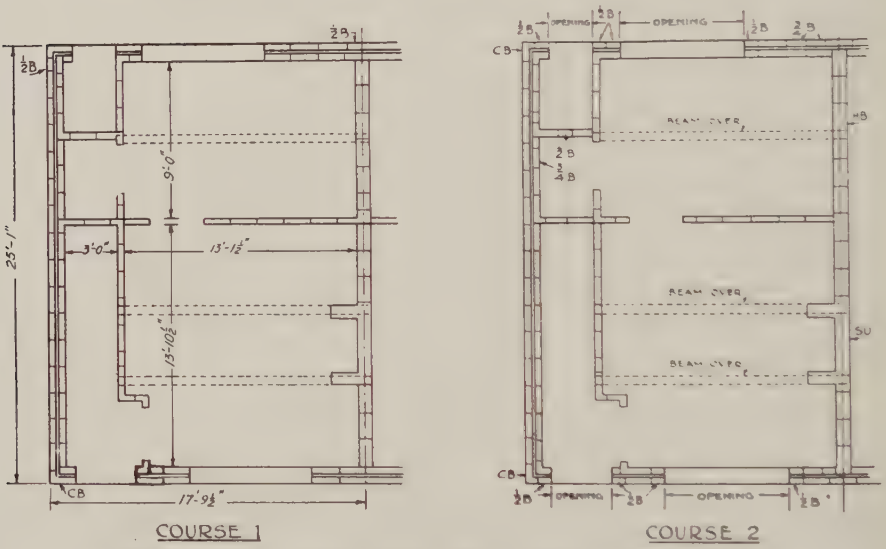


Fig. 515.—Concrete Houses at Castlenau for the London County Council.

In the following notes the various methods of concrete house and cottage construction are described, and the same methods also apply to the erection of concrete bungalows and garages. It will be realised that there are numerous special systems, some of which only differ from one another in small details; in these notes the various systems and methods have been grouped broadly under comprehensive headings, and the principles underlying their design and constructional methods dealt with from a general point of view.

Concrete-Block Walling

Cavity Slab Walls.—Owing to the condensation which occurs on the inner faces of solid gravel concrete walls used for domestic purposes, when solid blocks are adopted the walls must be built in two leaves with a continuous air space between them. (Attempts have been made to avoid this trouble by making solid blocks with gravel-concrete for half the thickness and clinker concrete for the other half, but this system does not seem to have met with success.) The usual method is to use slabs 18 in. by 9 in. by 4½ in., made of gravel concrete, for the outer leaf, and an inner leaf of clinker slabs of the same superficial area and of thicknesses between 2½ in. and 4½ in.; 2½ in. is sufficient thickness for the inner leaf of all ordinary



NOTE:— ALL WHOLE BLOCKS EXCEPT WHERE INDICATED AS FOLLOWS:—
¾ B = THREE QUARTER BLOCKS C.B. = CORNER BLOCKS S.U. = SMALL UNITS
½ B = HALF BLOCKS S.B = SPECIAL BLOCKS H.B = HOLLOW BLOCKS

Fig. 516.

cottage work, but in some districts the by-laws stipulate that no portion of the concrete shall be less than $4\frac{1}{2}$ in.

The method of setting out and laying the slabs is shown in *Figs.* 516 and 517. A 2-in. cavity is left between the two leaves, galvanised-iron wall ties being used to connect the leaves. *Fig.* 517 shows how the joints are staggered as in brickwork, using **L**-shape slabs at the quoins.

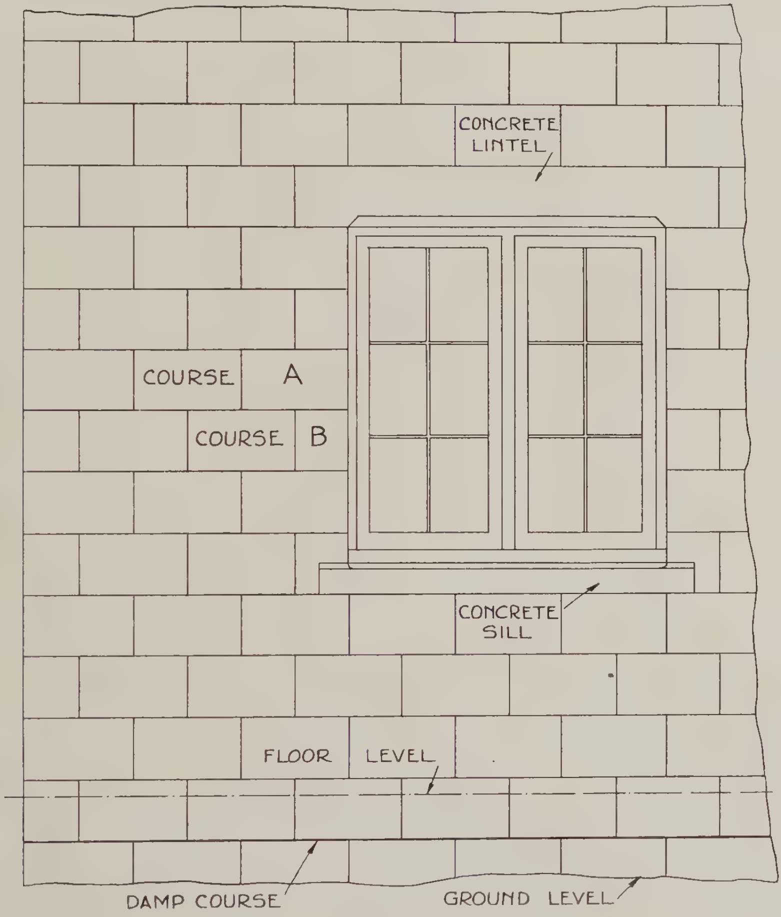

CONCRETE LINTEL
COURSE A
COURSE B
CONCRETE SILL
FLOOR LEVEL
DAMP COURSE
GROUND LEVEL

Fig. 517.

The wall footing and floor may be shown poured as a raft at one operation, thus saving formwork and simplifying concreting. The bottom course of walling should be laid so that the dampcourse is at a lower level than the floor. This is shown in *Fig.* 518. A few holes are formed in the outer wall at dampcourse level, so that any moisture collecting in the gutter between the two walls may escape.

The inner and outer divisions of the wall are tied together with wall ties at 3 ft. spacing horizontally and at intervals of 18 in. vertically. The ties should be galvanised or tarred and sanded, and they should have a dip or twist in the centre of their length which will prevent water running across them from the outer to the inner leaf. In placing them in the work they should be staggered, i.e., a tie should be placed in the centre of the space between the ties immediately above and below, and care should be taken that mortar is not allowed to drop on to the ties and remain there, as this will prevent the twist or dip being effective in throwing off the water, and if the tie is covered with mortar the whole width across the cavity it will become a means of conveying water to the inner leaf of the wall.

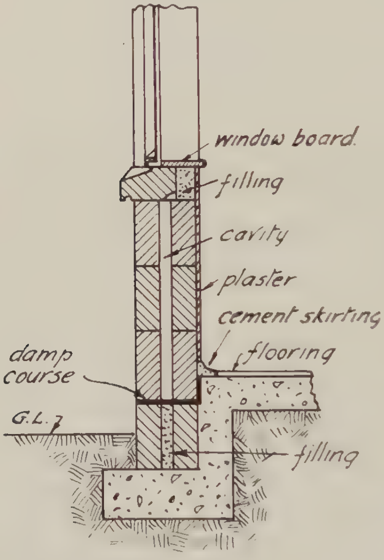


Fig. 518.

All window and door frames which occur in cavity walls where the head is exposed to the possibility of water dropping down the cavity should be covered by a layer of impervious material, which is built into the two thicknesses across the cavity to form a kind of gutter with the ends carried beyond the width of the frame to throw all water clear. In good class work 4 lbs. lead is often adopted for this, but in cottage work zinc or one of the many good waterproof coverings which are on the market can be used.

It must be understood that the outer thickness of walling, which is only 4½ in. thick, may not be entirely weatherproof, and the object of the cavity is to form a break between the outer and inner surfaces which will prevent the actual passage of moisture; any woodwork in the cavity which is not protected will therefore be liable to become damp and also to conduct damp to the inside of the house. The cavity should be well ventilated at the top and bottom to ensure a free circulation of air, as this will assist in keeping it as dry as possible.

Clinker blocks may be used for both leaves of the wall providing the exterior is rendered with cement to make it weatherproof. In this method it is also desirable to use corner and intermediate piers, either in reinforced concrete or gravel-concrete blocks, and reinforced concrete beams at floor and roof levels in order to take the floor joists and roof loads, for it must

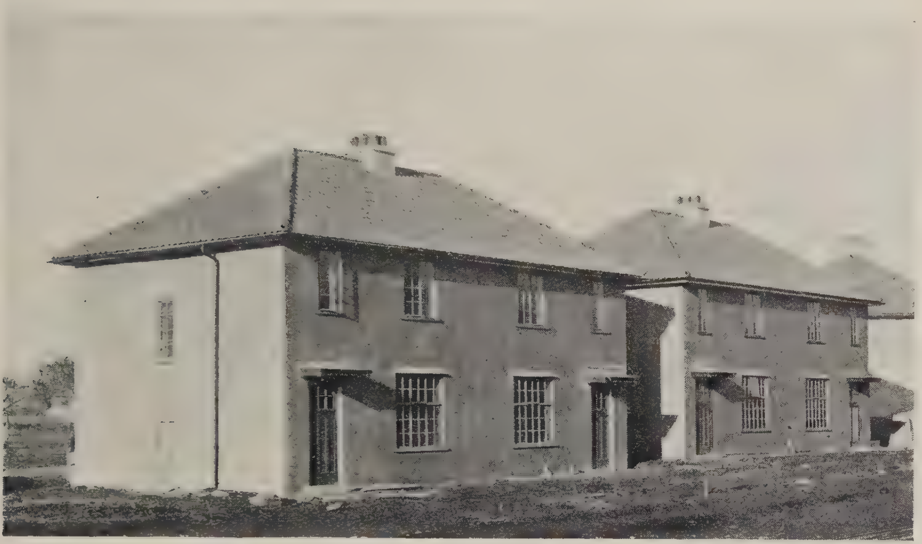


Fig. 519.—Concrete Cottages at Gosport.

be remembered that clinker concrete cannot be relied upon for these purposes. Also, under no circumstances should steel be embedded in breeze or clinker concrete. *Fig.* 520 shows the method of tying cavity slab walls on the "Fidler" system at the Becontree Estate of the London County Council.

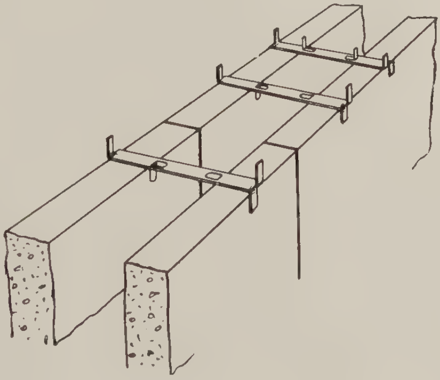


Fig. 520.

When concrete blocks are used, reinforced concrete lintels should be pre-cast and built in over door and window openings. These lintels should be at least 6 in. deep by the thickness of the wall by the width of the opening plus $4\frac{1}{2}$ in. bearing each end. Thus, over a 3-ft. opening in a 9-in. wall the lintel would be 6 in. deep by 9 in. wide by 3 ft. 9 in. long. Such lintels should be reinforced with at least two $\frac{3}{8}$-in. round rods placed 1 in. from the bottom and 1 in. from the sides, with the ends hooked. When the lintels are made the top should be marked and care taken to ensure that the steel is in the bottom.

Hollow Blocks.—There are various types of hollow blocks designed with the object of preventing condensation by providing air-spaces within the wall (see *Fig.* 521), and these are laid so that the solid portions of the block in each course do not come above the solid portions of the blocks in the courses above or below, so that the air has free circulation throughout the wall. When hollow blocks are used the cavities should not exceed one-third of the bearing surface, and the material around the cavities should be at least 2 in. thick. With plain rectangular blocks less thickness than 2 in. should never be adopted. The by-laws in some districts stipulate that with concrete blocks in external walls no portion of the concrete shall be less than 4½ in. thick; when such a requirement has to be met the use of hollow blocks is prohibited, and the only way to comply with the by-laws is to build continuous cavity walls consisting of two 4½ in. solid walls connected together with wall ties. In such cases the solid blocks 18 in. by 9 in. by 4½ in. are used.

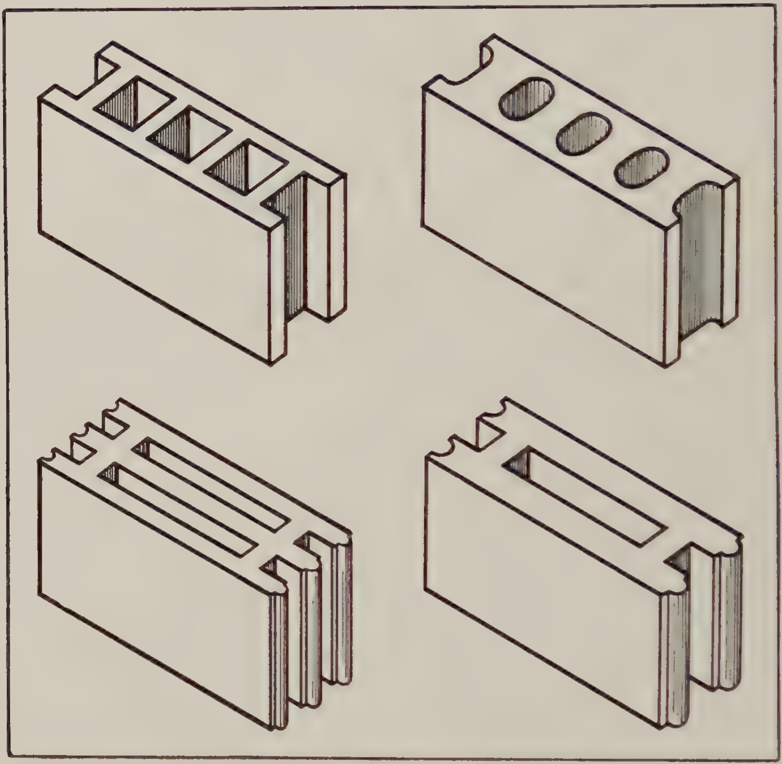


Fig. 521.

In the Regulations of the London County Council it is stated that where hollow concrete blocks are used in external walls they shall conform to the following requirements:

(*a*) The aggregate thickness, including any cavity, shall be at least 8½ in. measured at right angles to the face of the wall.

(*b*) The sides shall be at least 2 in. thick.

(*c*) The ends and any interior partitions shall be at least 1 in. thick.

(*d*) The clear unsupported span of any part of any side, end, or interior partition shall not be more than four times the least thickness of such part.

(*e*) The aggregate thickness of the material shall be at least 6 in. measured at right angles to the face of the wall.

The method of setting out and laying hollow blocks is the same as in the case of solid blocks. Care must be taken to prevent mortar dropping down the cavities, and for this purpose a piece of wood cut to the shape of the cavity may be inserted in the block before applying the mortar and pulled up by a ring previously screwed into it after the mortar is placed, so that any mortar that may be dropped into the cavity is removed.

Fig. 522.—Concrete Housing Estate at Dundee.

The methods of making various shapes of concrete blocks and slabs are dealt with in Part VIII.

Various types of tee-blocks are also used, some of which are illustrated in *Fig.* 523. These are used for forming cavity walls, and built with staggered joints so that the Tee-shapes, or lugs, on the two leaves rest on the projections of the lower courses. These projections are mortared, and thus act as wall ties. In some cases the projections are so arranged that air may circulate freely throughout the whole of the wall, while in other types the projections form piers at intervals along the wall with vertical air spaces between.

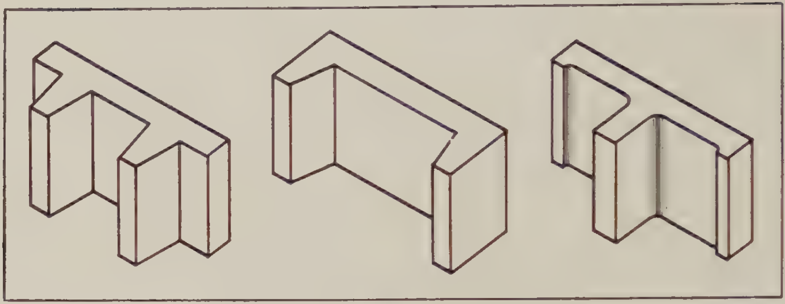


Fig. 523.

Solid Walls

Solid concrete walls are quite satisfactory for houses providing the concrete is sufficiently dense to prevent rain permeating through the walls and measures are taken to prevent condensation on the inside. The first requirement is readily met by following the principles of concrete making dealt with in Parts II and III. The second difficulty, the prevention of condensation, may be overcome by the well-known method of using plaster on the inner faces of the walls, but other means are generally used to avoid the high cost of plastering, and these are dealt with later.

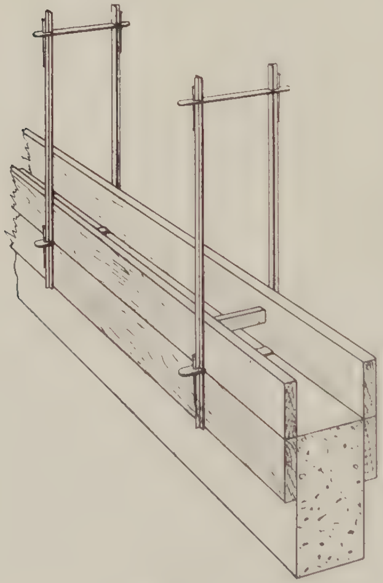


Fig. 524.

Solid walls for houses may follow usual practice so far as shuttering is concerned (see Part IV), but owing to considerations such as the frequent repetition of form sizes found in a large housing scheme, special types of shuttering have been developed for this class of work.

Fig. 524 shows one of the simplest methods. It consists of 2-in. tee-irons and metal strips a little longer than the width of the wall. These, and a few large nails or spikes, are all the equipment necessary to hold the shuttering in position. The metal strips are placed across the footings at intervals of about 5 ft., or less if required by the intervention of wall openings. Through the holes in these strips are passed T-irons about 4 ft. long, and these are firmly held by wedging with spikes. The T-irons are held in position in the same manner at the top. Against the inner (and flat) faces of the T-irons are placed wood planks, forming the shuttering between which the concrete is poured. The shuttering is easily stripped by removing the spikes and withdrawing the T-irons by lifting them upwards through the holes in the strips. The lower strips are, of course, embedded in the wall when the concrete is poured, and are removed by knocking them through the wall; this is easily done by a blow with a hammer at one end and a pull on the other, and is facilitated by giving them a blow to loosen them at the end of each day's work. The small holes left in the wall are made good with cement if necessary, and the faces roughcast outside and plastered inside.

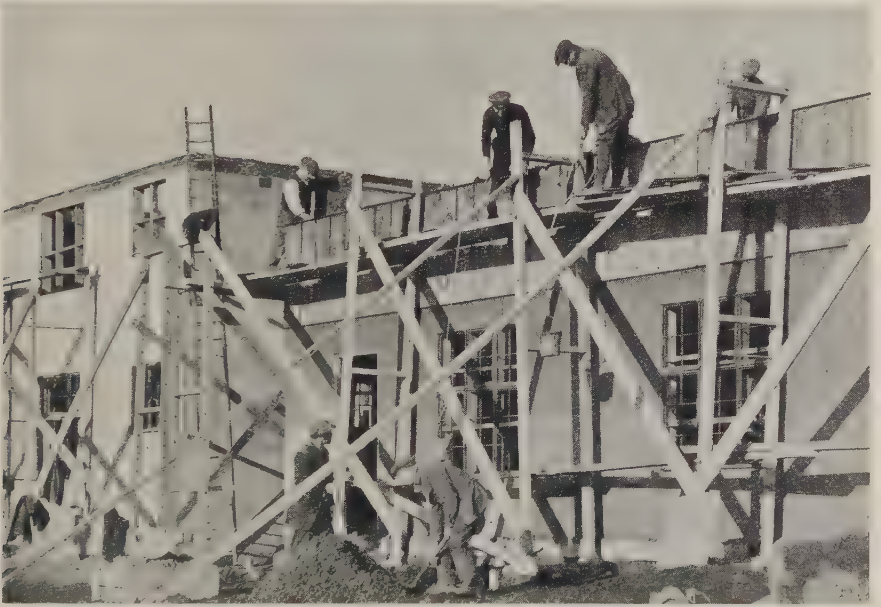


Fig. 525.—Concrete Houses during Construction at Gosport.

In view of the large number of houses in many schemes, formwork systems have been devised with the object of reducing the number of units by the use of forms covering large areas. One of these is shown in *Fig.* 525, in which the basis of construction is a light but strong form 6 ft. by 2 ft. All forms are of standard size except the four corner forms of each block and closures; each form presents a substantial surface to those adjoining, and each is secured to give rigidity and accuracy of position. When the first row of forms is set in position it is filled with concrete and the second row placed on and secured to it and to each other by bolts or pins.

When the second row is filled with concrete, the first is removed and secured on to the top of the second row, thus forming the third course, and this process is repeated up to roof height. Each course is 2 ft. high, and it has been found that the work is most economically managed when the gang is such that it can complete one course of a block of houses for both shuttering and concrete in a day.

Another method, in which still larger units are used, is shown in *Fig.* 526, where the method of construction is first to shutter the whole of the ground floor, erecting the wood forms on the footings and strutting them in position. For the ground floor of a pair of houses, seven sets of shutters are used; one for each end wall, one for the front of each house, one for the back of each house, and one for the party wall. Upper floors require a similar number of sets of shutters. These forms are built up of 7-in. by 1-in. and 7-in. by 1½-in. boards nailed to 4-in. by 2-in. studs at 2-ft. centres. The shutters are stopped off to allow for door and window openings.

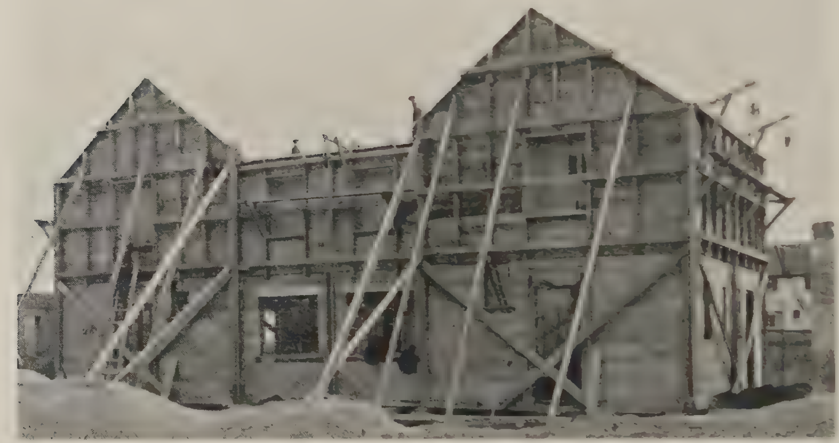


Fig. 526.—Shutters to First Floor in Position.

Fig. 527 shows a method in which the walls are poured horizontally beside the site of the houses and erected by crane. Each pair of houses consists of fourteen slabs; the front and back of each house is made up of two slabs, one for the ground floor and one for the upper story (eight slabs in all for the front and back walls of the pair); the end walls of the pair are formed of two slabs, one for the ground floor and one for the upper floor; while the party wall to each floor is pre-cast as one slab.

These slabs are moulded on wood platforms beside the site of the house of which they are to form part. Window and door frames are placed in position before concreting commences so that the labour necessary after the walls are erected is reduced to a minimum and at the same time the woodwork is securely fixed in the wall.

The use of metal forms is shown in *Fig.* 528. These shutters are usually made of a uniform height of 2 ft. and in various widths so that any odd length of walling can be made up. They are fitted with flanges on all four sides, through holes in which the parts are wired together. Only sufficient plates are necessary to build two courses, as the lower course is released and erected on top of the second course as the work of placing the concrete proceeds around the house.

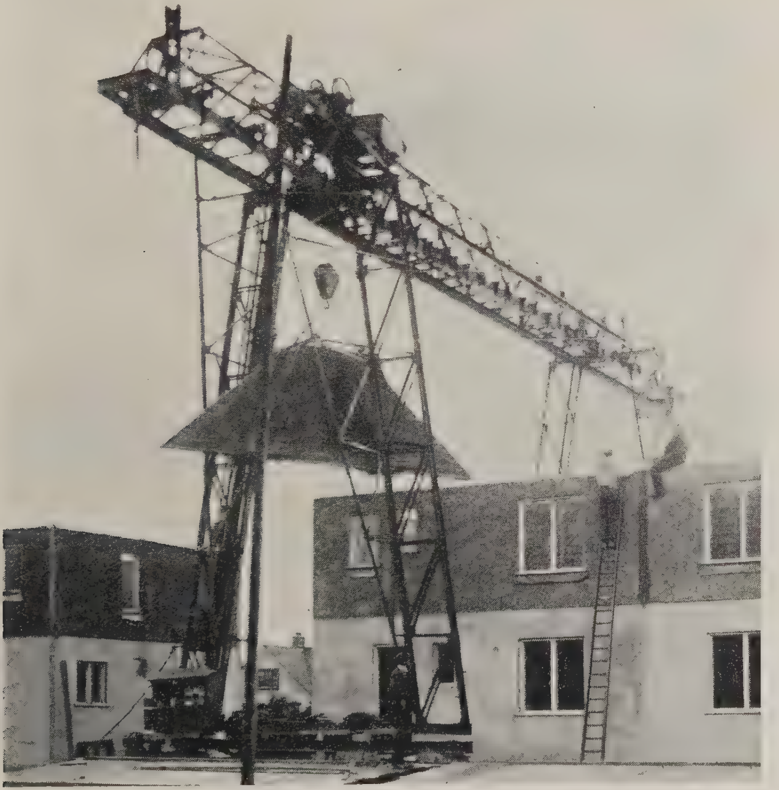


Fig. 527.—Lifting a Large Section.

Thickness and Reinforcement.—The thickness of wall required will depend on various considerations apart from any question of by-laws, such as (*a*) the nature of materials available for concrete; (*b*) whether building is in very exposed situation; and (*c*) nature of surface finish to be applied to the wall, if any. The essential point is, of course, that of making the wall sufficiently strong and weathertight for its purpose. It is necessary to employ good concrete which is proportioned and mixed to give a dense mixture, and this must be filled in and thoroughly tamped. Generally speaking, the thickness will vary from 4 to 8 in., and provided the work is properly executed the walls will be weather-resisting without the addition of any surface coating or special waterproofing compound. The addition of piers at the angles and other suitable points is helpful, and they can sometimes be introduced to improve the design if considered in conjunction with the elevations of the whole building.

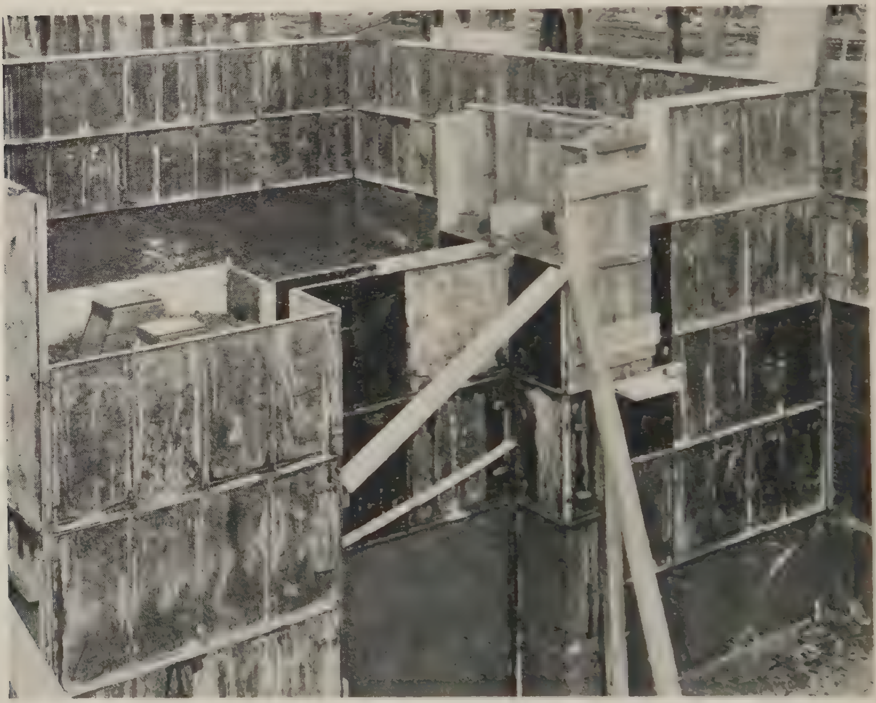


Fig. 528.—Concrete Chimneys in Course of Construction.

When piers are employed the panels between can be constructed with concrete 4 in. thick only, and will be found quite satisfactory if a little reinforcement is added. Door and window frames should be cast in the work as it proceeds, as this will save expense in the shuttering and they will

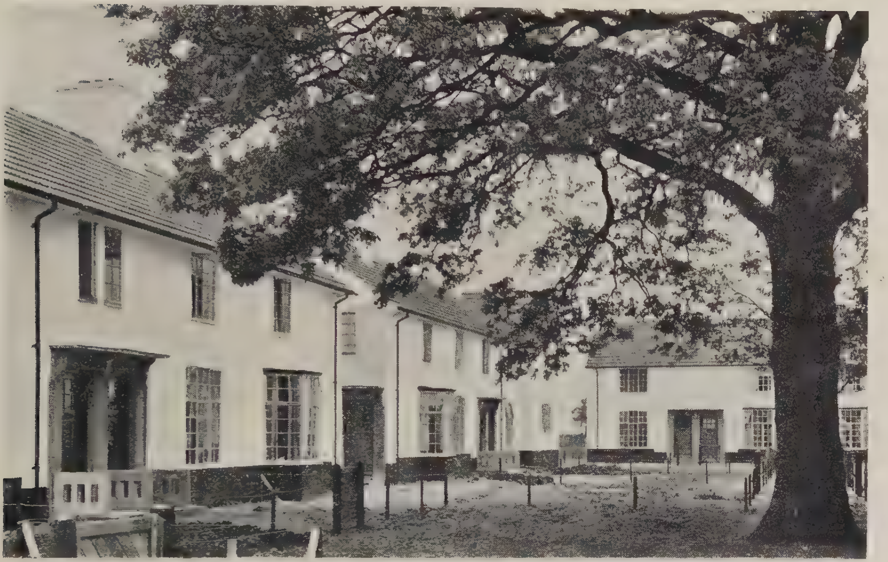


Fig. 529.—Concrete Houses at Welwyn Garden City.

be securely fixed, especially if a few strips of hoop iron are attached or nails are driven in and left projecting so as to tie with the concrete when it is set.

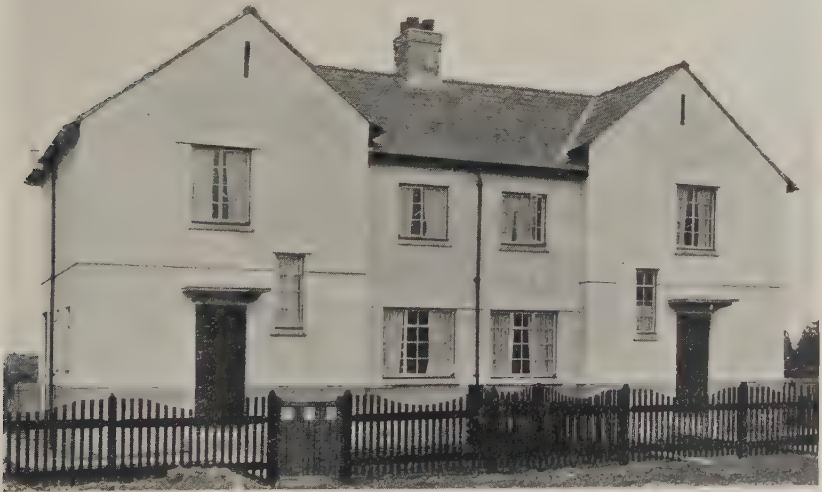


Fig. 530.—Pair of Concrete Houses at Gloucester.

Reinforcement may be introduced into the walls for the sake of preventing cracks, more especially in large areas. This reinforcement should consist of light steel mesh or rods, and where the latter are employed they may be ⅜-in. diameter or ¼-in. diameter, spaced at 18-in. or 24-in. centres both horizontally and vertically. They should be hooked at the ends and attached to vertical rods in the piers when the latter occur, and the vertical rods should be attached to the foundation concrete.

Two ½-in. rods should be placed horizontally over each opening and extend at least 6 in. on each side beyond the jambs, and diagonal rods should be placed across the corners of such openings as near to the frame as possible.

Preventing Condensation

As an alternative to plastering, condensation may be prevented by the use of clinker for the inner face of the wall, the procedure being to place wire netting vertically within the shuttering and to pour gravel concrete on the outer side and clinker on the inner side of the netting. The two mixes should be poured at the same time so that they bond together through the meshes of the wire.

Cottage walls may be built entirely of clinker providing the outer faces are thoroughly waterproofed with a cement rendering (see Part IV). In this case the walls are usually made 8 in. thick, using clinker from ¾ in. down. When clinker is used throughout the walls present an excellent key for plaster. The use of smaller clinker aggregate and smooth wood or metal shutters will produce a good level surface which may be treated with a coat of stiff limewash to fill the small interstices followed by distemper, or wallpaper may be used direct on the wall.

Pier-and-Panel Walling

Walls formed of piers at intervals around a house with the intervening spaces filled in with pre-cast concrete slabs have been used for many thousands of houses. The principle is shown in the plan in *Fig.* 531, although several different methods have been evolved of jointing the slabs to the piers.

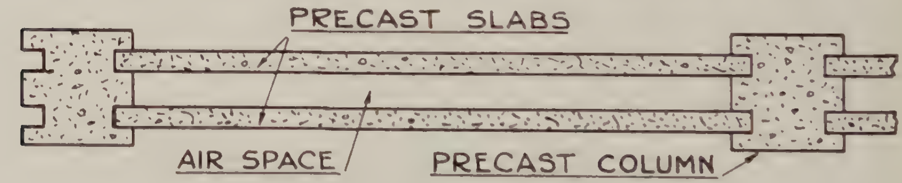


Fig. 531.

Fig. 532 shows houses being built by this method. In this system the wall is formed of pre-cast slabs laid on edge one above another, with a vertical space between each tier of slabs which is filled in with concrete poured *in situ*, thus forming a column and binding all the slabs together at their ends. The slabs are 3 in. thick by 8 in. high. The ends are splayed in order to get a stronger bond at the piers, and the length of the slabs is 3 ft. 8 in. on the longer face and 3 ft. 6 in. on the shorter face. The piers measure 8 in. across the face of the wall, and occur at 4-ft. centres all round the cottages. The walls are formed of two leaves, with a 2-in. cavity between, making a total thickness of 8 in. The slabs are of the same size for both leaves, and no variation is made in the concrete for the external and internal walls.

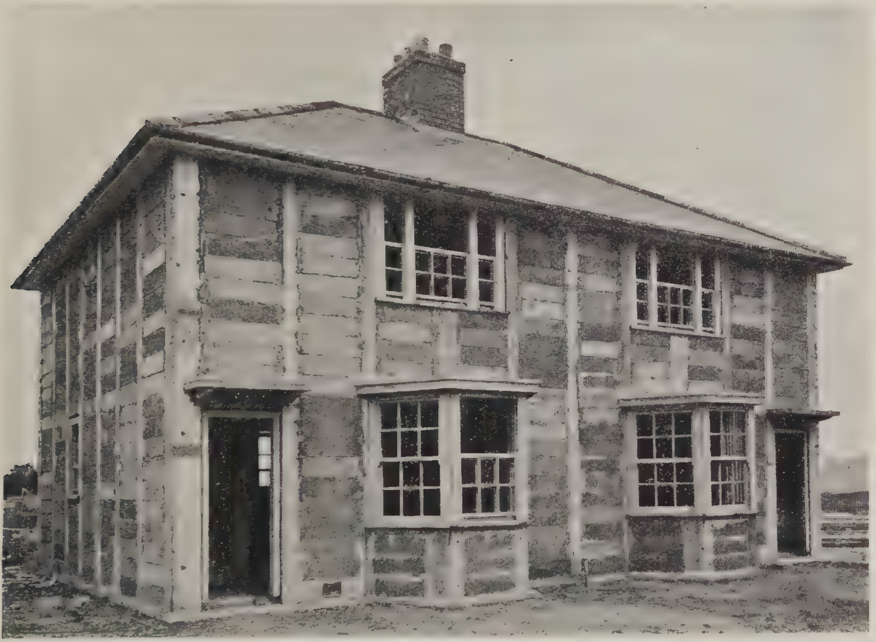


Fig. 532.—" Pier-and-Panel " Concrete Houses during Construction at Birmingham.

The method of erection is to place the slabs on edge one above another without horizontal mortar joints, strips of wood, which also form the sides of the piers and are afterwards removed, being used as distance pieces. The distance between the slabs along the outside of the wall is 6 in. and on the inner face 4 in., the difference being accounted for by the chamfered edges. As the slabs are laid shuttering is erected to enclose these spaces on the outer faces of the two leaves forming the wall, and pieces of wood are placed inside the cavity 3 in. from the ends of the slabs. Within this shuttering concrete is poured *in situ*, forming a solid pier throughout the height of the wall at 4-ft. centres.

Fig. 533 is a plan showing another method of bonding pre-cast slabs and *in situ* columns.

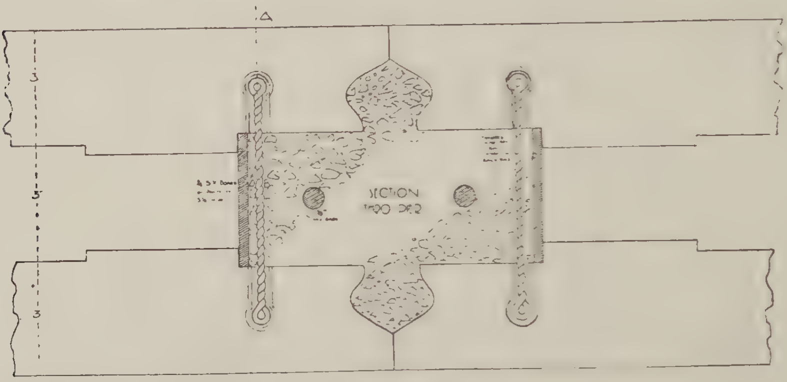


Fig. 533.

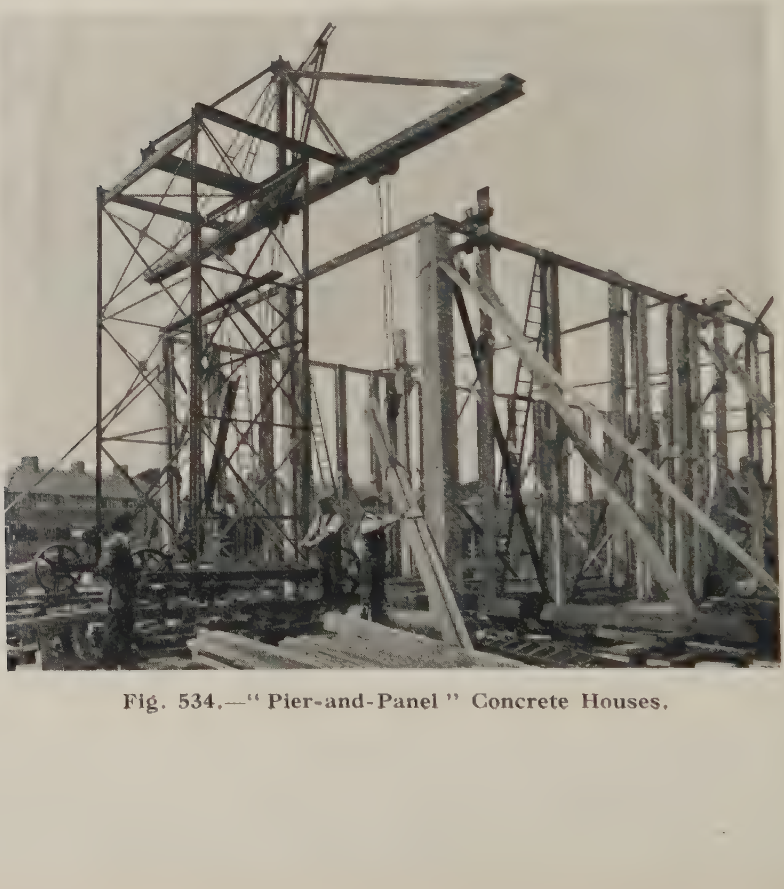


Fig. 534.—" Pier-and-Panel " Concrete Houses.

In other systems pre-cast piers, with grooves throughout their height on two sides, are first erected, and pre-cast slabs slotted into the grooves (*Fig.* 534).

Reinforced Concrete Frame Construction

Another method (illustrated in *Figs.* 535-6) is to erect the frame of the house or houses in reinforced concrete columns and beams, filling in the spaces between these members with concrete slabs. In the method illustrated the beams are carried on lugs cast on the piers, the piers and beams being pre-cast on the site. The wall spaces may be filled with *in situ* concrete poured between shuttering, or with pre-cast slabs ; in the latter case grooves are cast in the piers to take the ends of the slabs.

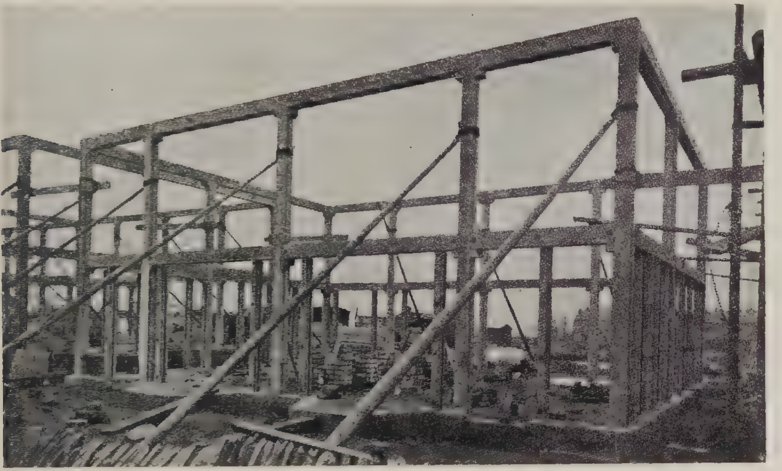


Fig. 535.—Reinforced Concrete Frame Construction.

A similar method makes use of a steel frame in place of the reinforced concrete frame. The steel structure is quite independent, and the spaces are filled in with concrete on steel mesh reinforcement.

Asbestos-Cement Sheets

For bungalows and garages asbestos-cement sheets may be used as shuttering and filled in with concrete to form a solid wall. The sheets are, of course, left in position. If sheets sufficiently thick to keep out the weather are used the filling may be of clinker concrete if the walls are only to carry light roof loads, and there is no need to roughcast or render the exterior. Also, the asbestos-cement sheets on the inner face eliminate the need for plastering.

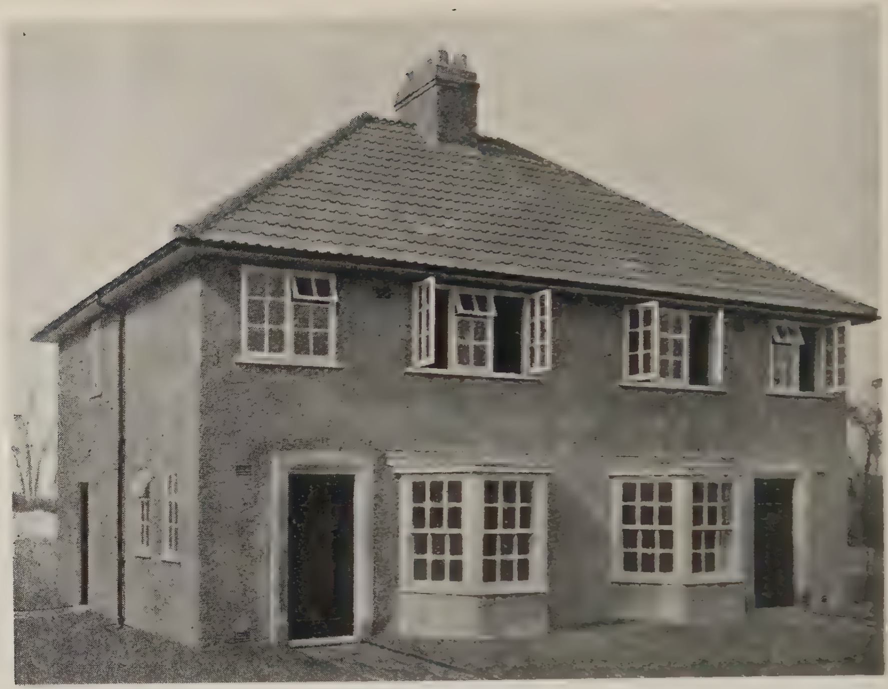


Fig. 536.—Reinforced Concrete Frame Houses.

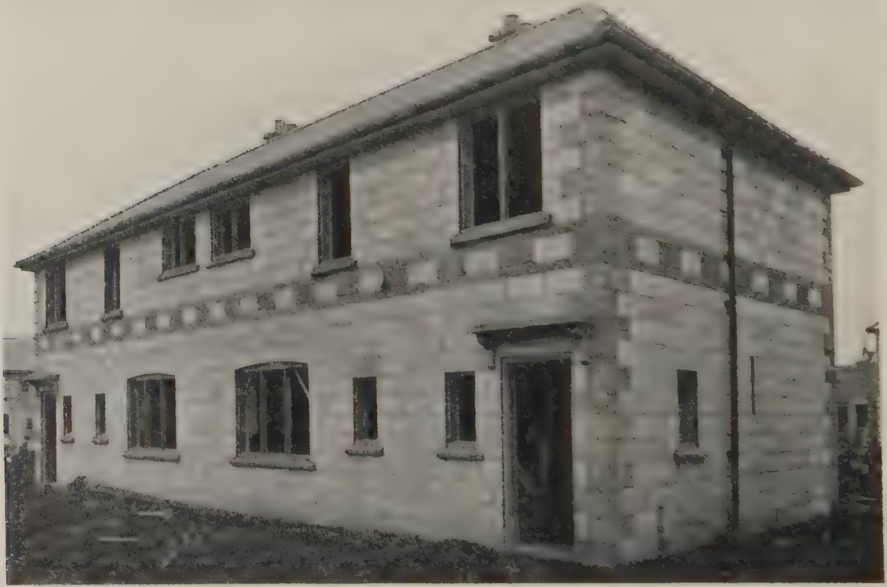


Fig. 537.—Concrete Houses for Liverpool Corporation, with Quoins and String Courses in grey, remainder white.

Floors, Partition Walls, Staircases, etc.

Concrete floors for houses follow usual practice. The reinforcement will be specified by the architect. Methods of formwork and placing are described in Part IV.

Partition walls are usually built of clinker slabs, the manufacture of which is described in Part VIII. Concrete staircases are dealt with in Part IV.

The roof may be either flat, in which case the information relating to floors is applicable, or pitched ; pitched roofs may be covered with concrete tiles, either interlocking or Broseley pattern. Details of the manufacture of concrete tiles are given in Part VIII, while the method of laying follows ordinary tiling practice.

Chimneys are usually built *in situ* by methods similar to that shown in *Fig.* 528. Methods of manufacturing pre-cast sills, steps, hoods, or other details are described in Parts VII and VIII.

GARAGES

If one considers the cost of a garage, or similar type of building often built of wood, over a period of twenty years or so, it will be found that the extra cost of a concrete structure will be more than repaid by the absence of repairs or maintenance costs, and the fact that at the end of the period the concrete structure is in as good condition as when built, whereas a wood structure would have suffered very considerable deterioration. In addition there is the further advantage, and a very important one in the case of a garage to house an expensive motor-car and in which the presence of petrol adds to the fire risk, that the concrete structure is the best fire-resisting material obtainable for building construction.

The construction of the walls and roof of a garage follow the same practice as described for cottage and bungalow walls ; the same types of walling may be adopted, and the same methods of construction used. If desired, the exterior appearance of the garage may be enhanced by any of the methods described in Part III. The size of the garage will, of course, depend on the size of car, or number of cars, it is to accommodate, allowing ample space around the car for movement when effecting adjustments. Space for a bench at the far end is also an advantage.

If the site is good a floor of 4 in. of plain concrete is sufficient. On doubtful soils it is advisable to place a mat of steel rods 1 in. from the bottom of the floor slab ; the rods should be ½ in. diameter, spaced at 6-in. intervals each way, and wired together at the crossings. The floor should be laid to a slight fall from the sides to the centre, where a drainage channel should be formed, keeping the floor level across the longitudinal section. The drainage channel should extend the full length of the floor, and dis-

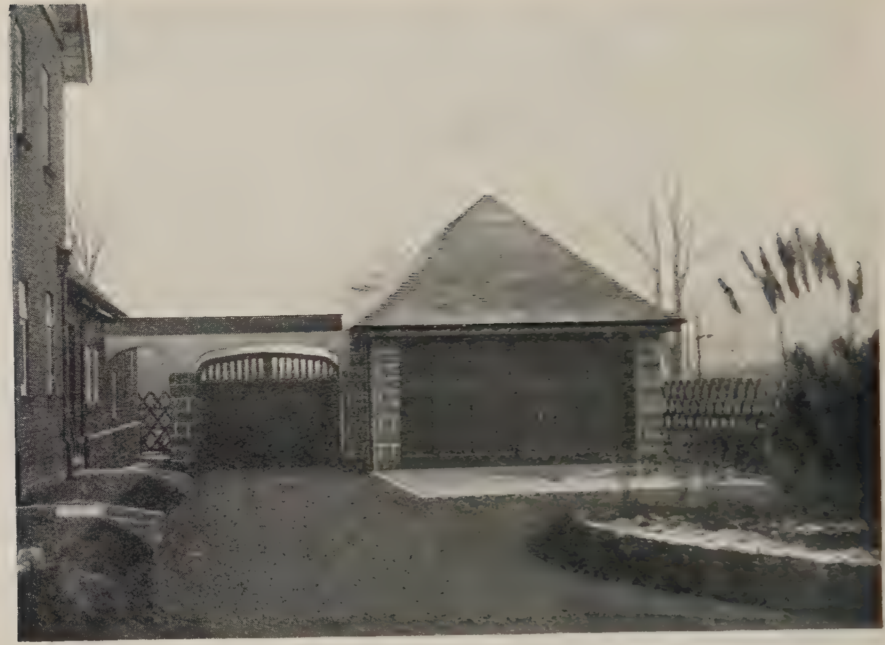


Fig. 538.—Concrete Garage for Four Cars, built of Concrete Blocks.

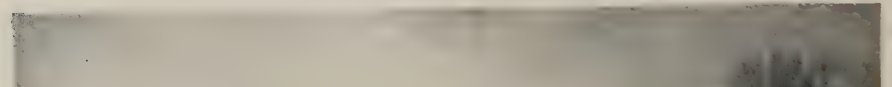


Fig. 539.—Concrete Garage for Hotel at Windermere.

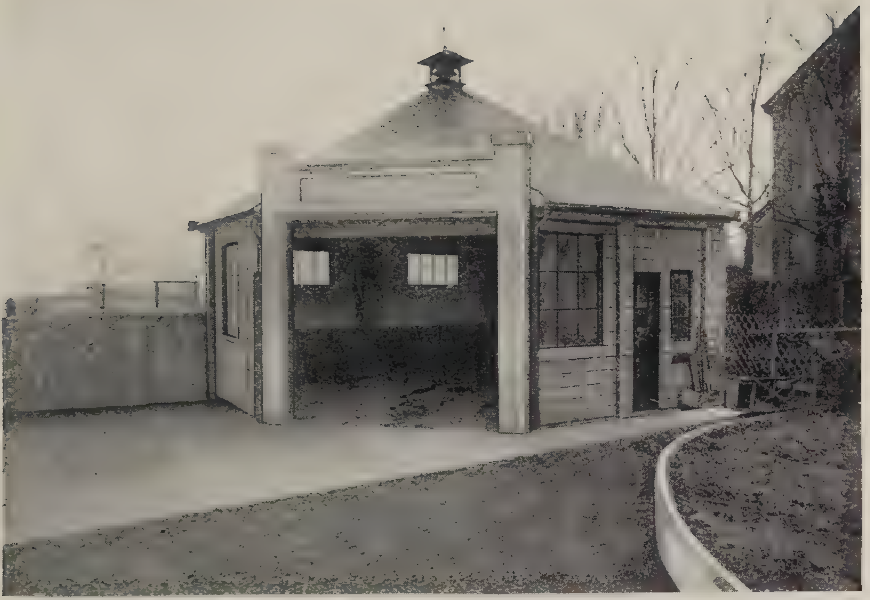


Fig. 540.—Private Garage built with Concrete Blocks 4½ in. thick.

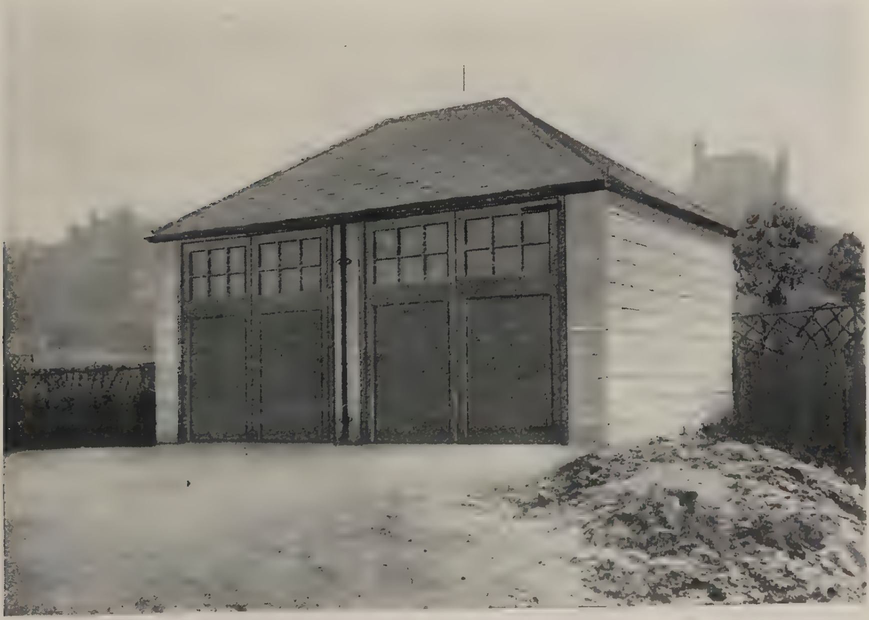


Fig. 541.—Pair of Lock-up Garages built of Hollow Concrete Blocks.

charge into a gulley outside. As the presence of oil is destructive to rubber tyres, the surface of the floor should be treated with silicate of soda, as described in Part V, so that it will be non-absorbent and can be washed clean should oil be spilled on to it. For a structure such as this the floor may generally be carried under the walls, and the walls built direct on the edges of the slab, in order to avoid separate wall footings.

If an inspection pit is required it should be constructed before the floor slab is laid. A useful design is given in *Fig.* 543. The pit should be about 6 ft. long by 3 ft. wide by about 4 ft. 6 in. deep with projecting ledges on each side to take movable boards 3 ft. 6 in. from the top. The walls should be 9 in. thick and the bottom 6 in. thick, recesses being formed at a convenient level in each side wall to take small tools. The pit is covered in with 2-in. boards fitted with sunk lifting handles, and a rebate is formed in the top of the walls of the pit to take these boards. If the pit is provided inside the garage it will, of course, be necessary to do all car washing outside, as the water would collect in the bottom of the pit and be difficult to remove.

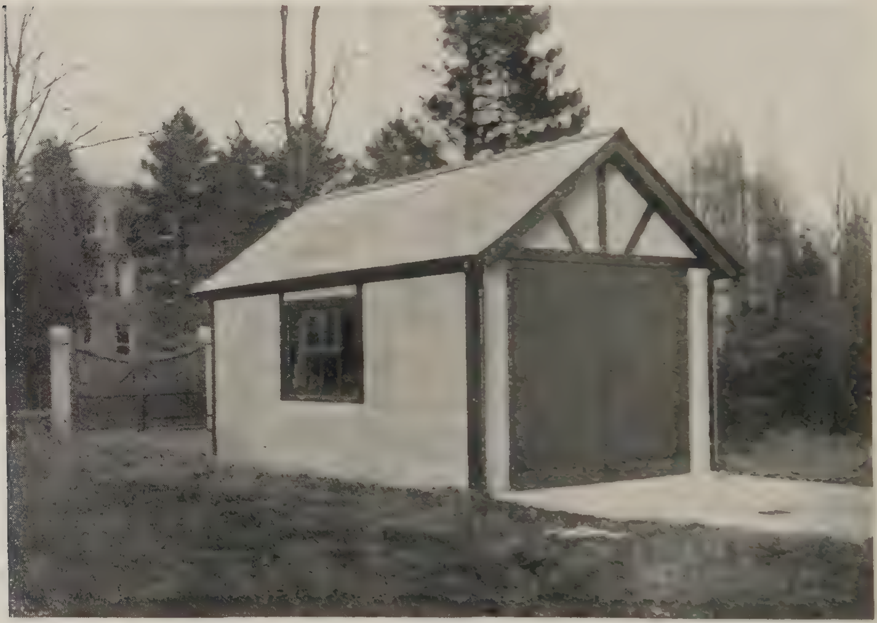


Fig. 542.—Concrete-Block Garage.

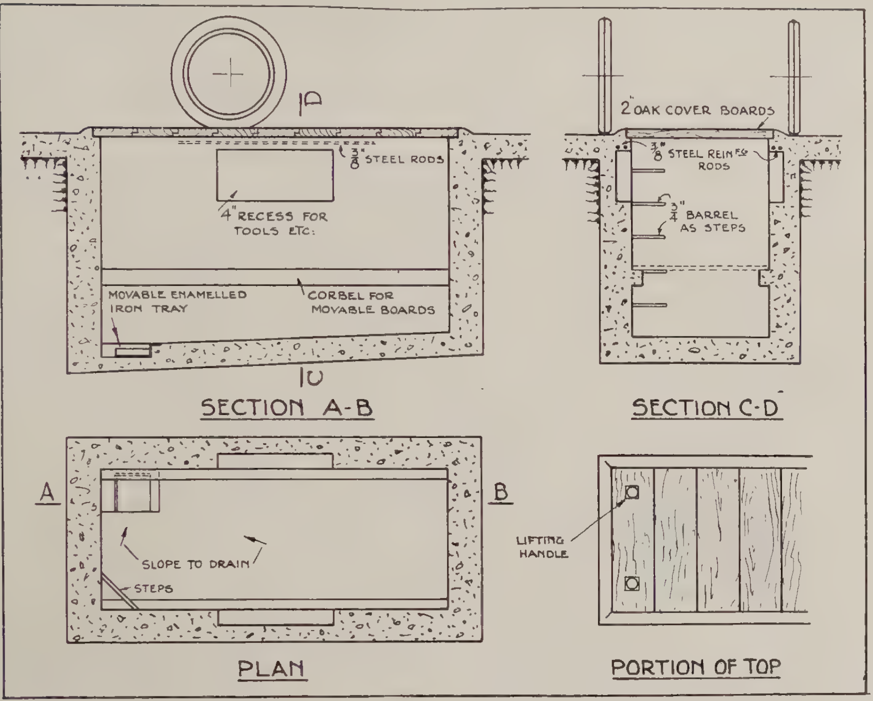

2" OAK COVER BOARDS
3/8" STEEL RODS
4" RECESS FOR TOOLS ETC.
MOVABLE ENAMELLED IRON TRAY
CORBEL FOR MOVABLE BOARDS
SECTION A-B
3/8" STEEL REINFG RODS
3/4" BARREL AS STEPS
SECTION C-D
A
B
SLOPE TO DRAIN
STEPS
PLAN
LIFTING HANDLE
PORTION OF TOP

Fig. 543.

CONCRETE ON THE FARM AND ESTATE

The maintenance of outdoor units and utensils, of small buildings and roadways, is no small item in the upkeep of farms and estates, and there are few structures and units more liable to decay. Dilapidated buildings, fencing, troughs, etc., are a common sight which can be avoided, and that without additional cost, by the use of concrete.

Concrete fence posts are now replacing wood on most of the railways and on a very large number of estates. They form an enclosure that does not rot at ground level and with much greater strength than a wood fence. The method of making the posts is dealt with in Part VIII. Concrete fencing (*Figs.* 544–5 and 696–701) may follow any of the usual types, with plain or barbed wire stretched between the posts or with iron tubes passing through holes in the posts. Special corner and straining posts (*Fig.* 708) are, of course, necessary. Once erected a concrete fence is practically everlasting, thus saving the cost of periodical repair and renewal. The close fencing in *Fig.* 544 is formed of pre-cast units, that is, the posts, rails, and panels are

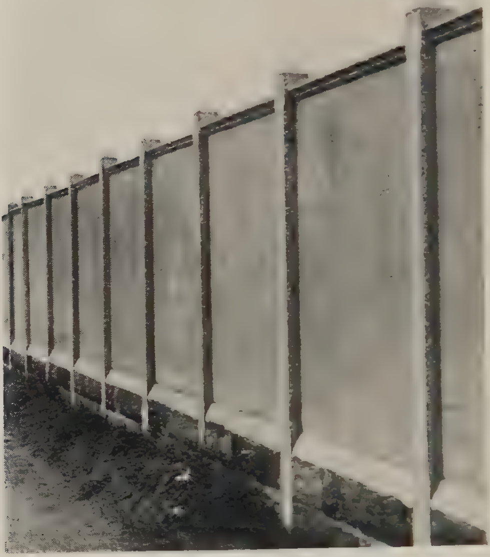


Fig. 544.—Close Fencing.

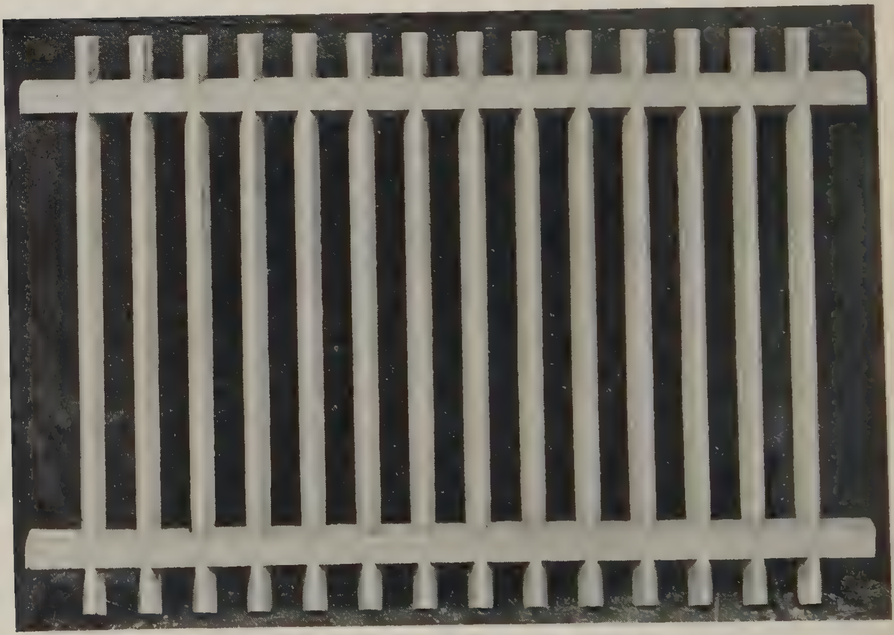


Fig. 545.—Section of Pale Fencing.

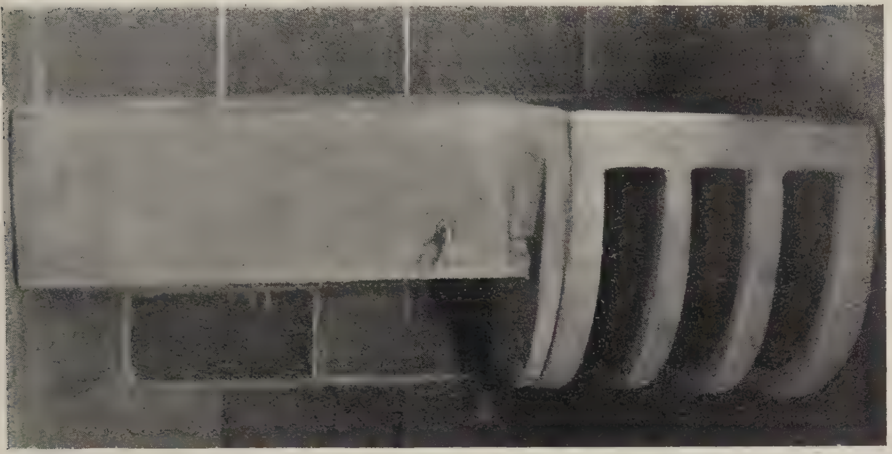


Fig. 546.—Concrete Manger and Hay Rack.

made separately and grouted in position. The posts are made in post-moulds of the usual pattern ; the rails in wood moulds shaped to give an attractive outline to the top rail and a sloping side to the bottom one ; the panels are made in wood trays of the desired dimensions. Grooves are cast in the posts to take tenons on the ends of the rails and a tongue on each side of the panel. Grooves are also cast in the underside of the top rail and the top of the bottom rail to take tongues on the top and bottom edges of the panel.

A method of making troughs in wood moulds is described in Part VII. Other types of troughs, mangers, and bins are seen in *Figs.* 546 to 553,

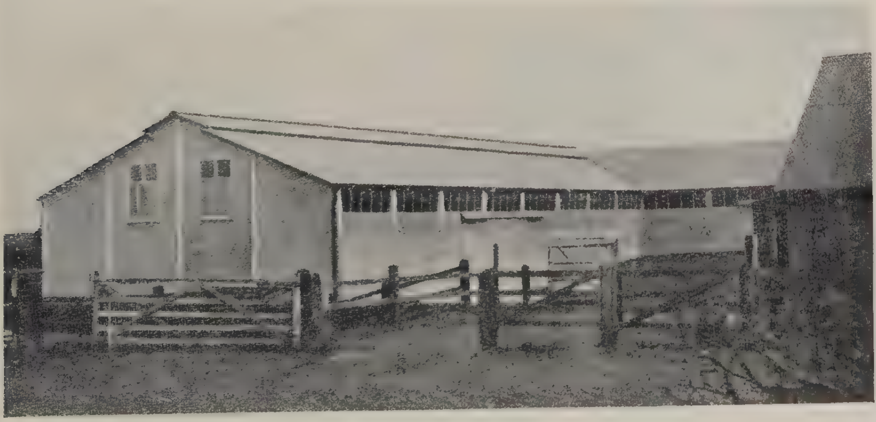


Fig. 547.—Concrete Cow-Houses at Swindon.

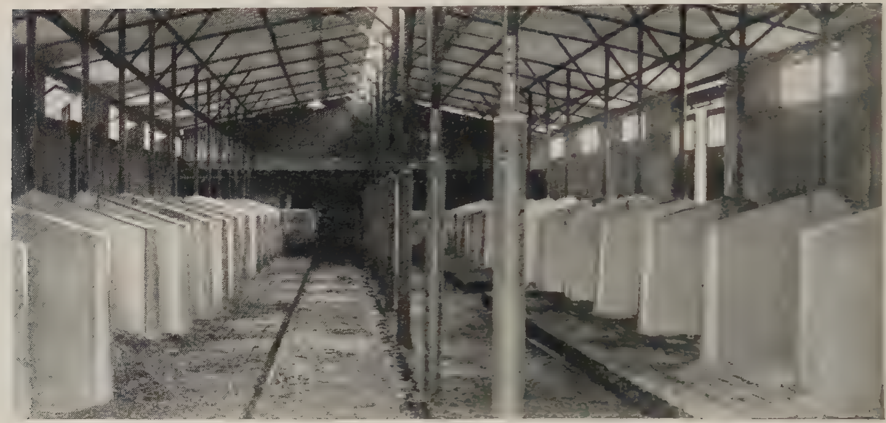


Fig. 548.—Interior of Cow-Shed, showing Concrete Floor and Concrete Stalls.

suitable for horses or cattle. Whatever the shape or size of troughs required it will be found a comparatively simple matter to devise moulds for their production in concrete, or they may be obtained ready-made from pre-cast concrete makers.

Figs. 548 and 549 show interior views of concrete cow-stalls, while *Fig.* 547

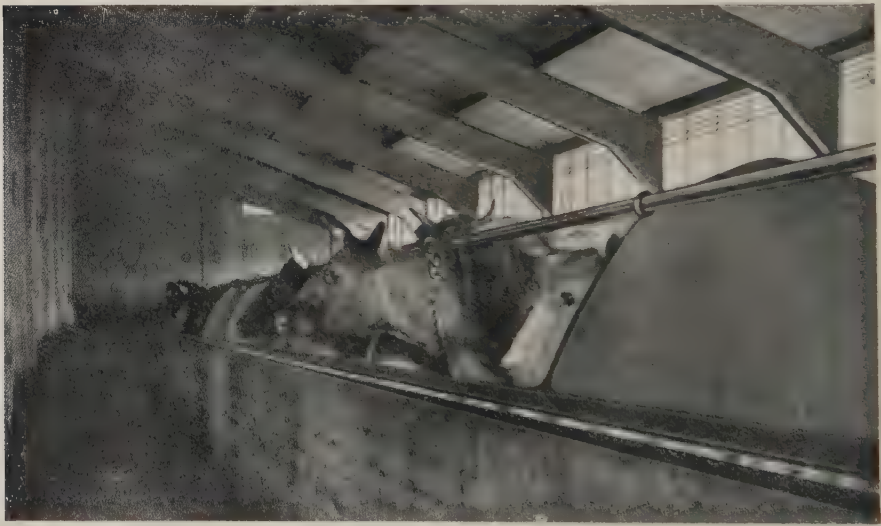


Fig. 549.—Interior of Cow-House, showing Reinforced Concrete Roof Principals.

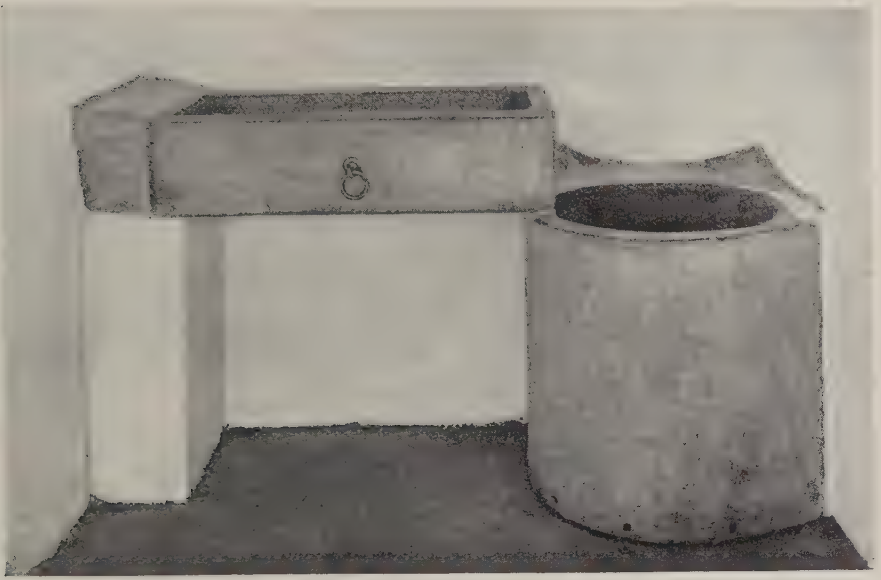


Fig. 550.—Concrete Manger and Water Tank.

Fig. 551.—Concrete Stall Divisions at Swindon.

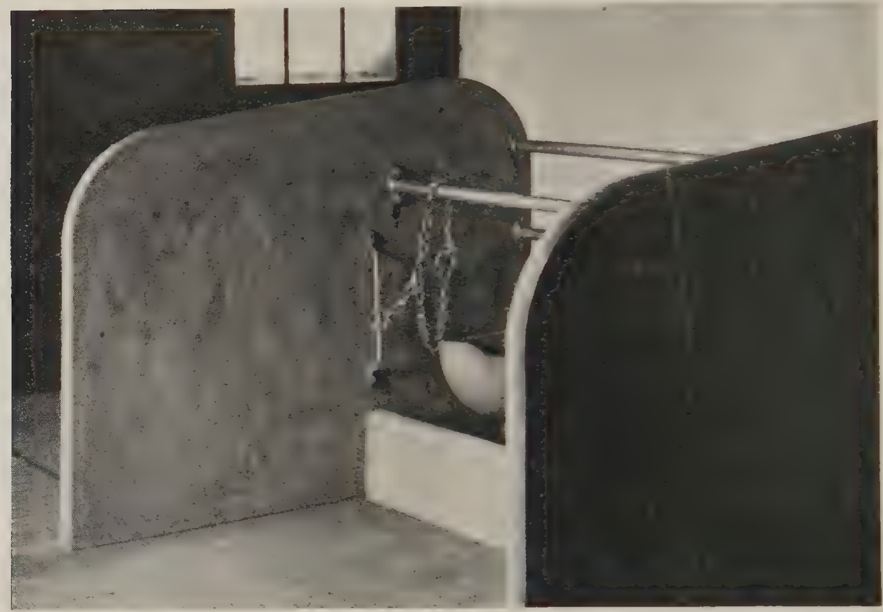


Fig. 552.—Concrete Stall Divisions and Trough.

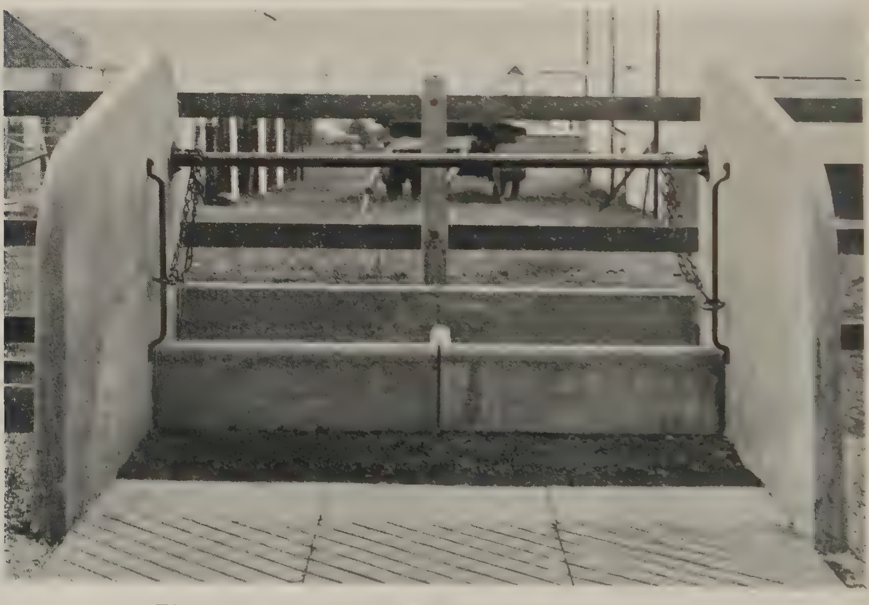


Fig. 553.—Concrete Stall Divisions and Trough.

is an exterior view of an all-concrete cow-house. To meet the requirements of the Ministry of Agriculture it is now almost imperative to make use of concrete in cow-houses ; the cleanliness and sanitation of the building and the health of the cattle can be ensured in no other way. Thus in addition to saving on the upkeep of the building, the farmer is able to command a better market for milk produced under sanitary conditions and also benefits by the better health of his cattle.

Generally the construction of a concrete cow-house follows the methods of building concrete bungalows or other one-story structures. The outer walls may be either monolithic or built up of blocks or slabs. Asbestos-cement sheeting is generally used for roofs. On a good soil a 4-in. concrete floor will be sufficient, laid to fall towards the centre and with gulleys to drain to a sump away from the building. The stall-divisions may be built *in situ* or pre-cast ; a thickness of 2½ in., with a mesh reinforcement, is ample. Feeding troughs are pre-cast and fixed in place by bolting through to the wall or by resting on supporting brackets. Rings may be cast in the troughs for fixing halters.

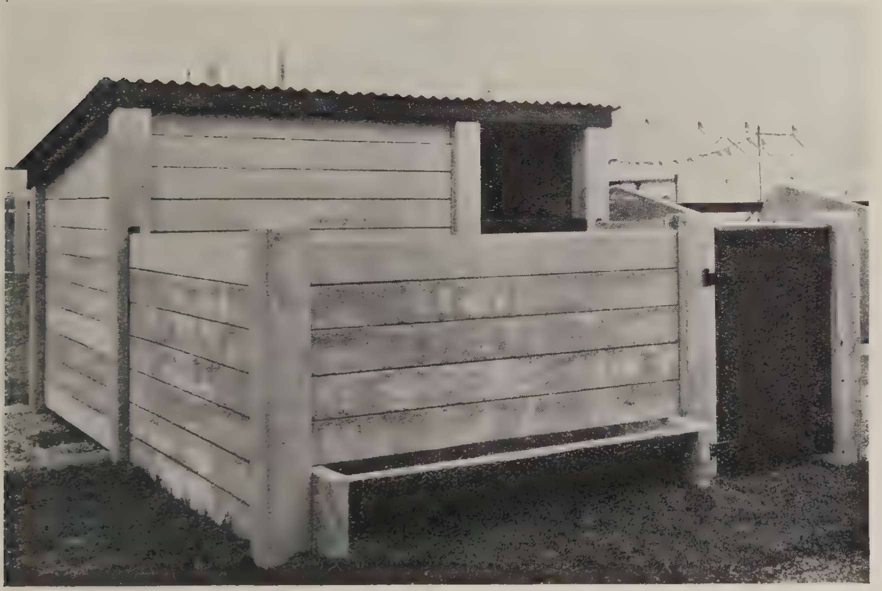


Fig. 554.—Concrete Pig-Sty.

Fig. 554 shows a pig-sty built of pre-cast concrete units. The method of construction is clear from the photograph. It consists of pre-cast concrete slabs slotted into grooves in pre-cast posts. For this type of structure, which carries no loads, there is no need for heavy reinforcement ; the units are subjected to greatest stress when they are handled during erection and by the weight of animals rubbing or pushing against the sides. In the posts, four vertical $\frac{3}{8}$-in. rods, wired at intervals, should be ample ; the slabs should be reinforced with three $\frac{3}{8}$-in. rods, also wired together. There are many advantages in this type of structure, which can be readily dismantled and re-erected on another site when desired.

In *Fig.* 555 is shown a useful and indestructible concrete farm shed built of reinforced concrete posts and roof trusses and covered with asbestos-cement sheeting. If desired, of course, the sides of such a shed may be filled in with concrete slabs to any height.

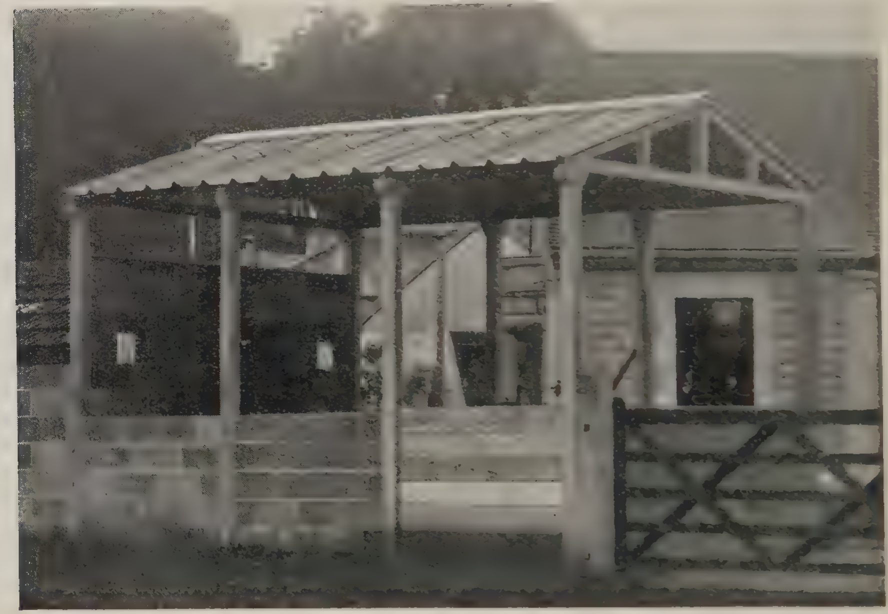


Fig. 555.—Concrete Farm Shed.

A concrete rick-stand, which cannot rot or be damaged by vermin, is seen in *Fig.* 556. This is made entirely of pre-cast units. Concrete beams radiate from the centre support to the outer posts, and into these are slotted the radial beams.

Figs. 557 and 558 show one of the latest developments in the effort of the farmer to introduce modern practice into agriculture, namely, the use of concrete roads. There is no need to stress the advantages of this type of road for farm use : by the use of this material farm roads are avail-

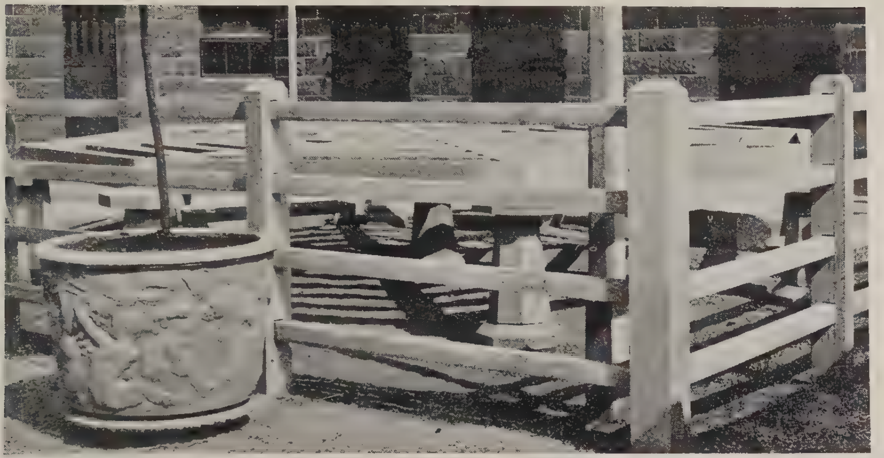


Fig. 556.

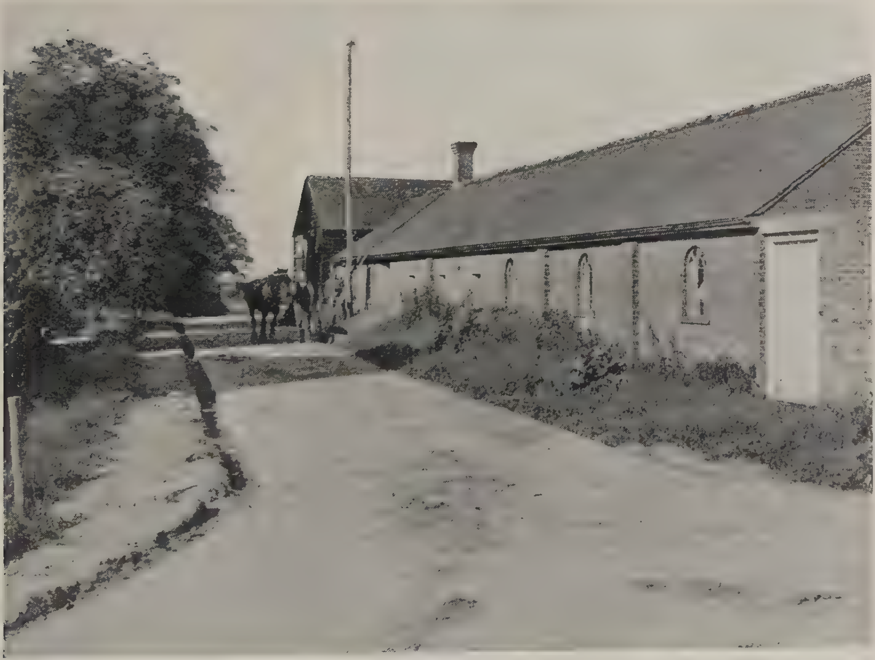


Fig. 557.—Concrete Farm Road.

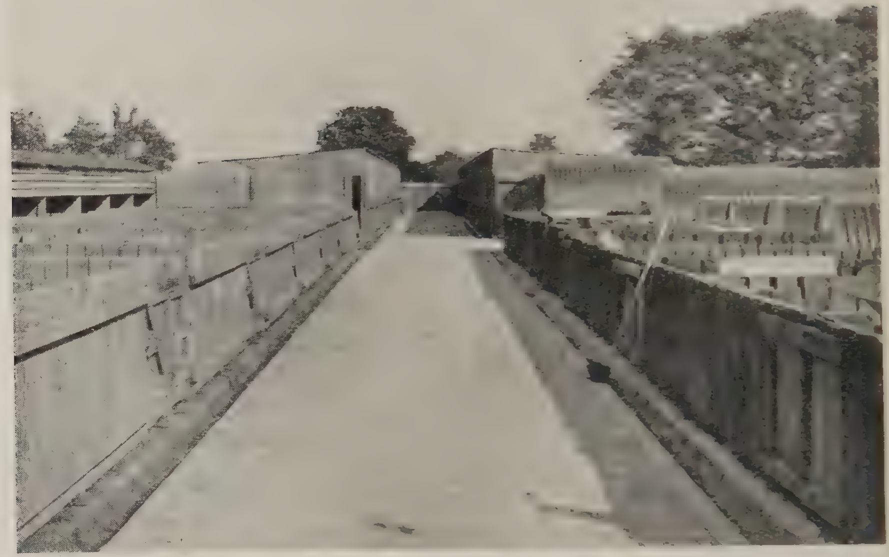


Fig. 558.—Concrete Farm Road.

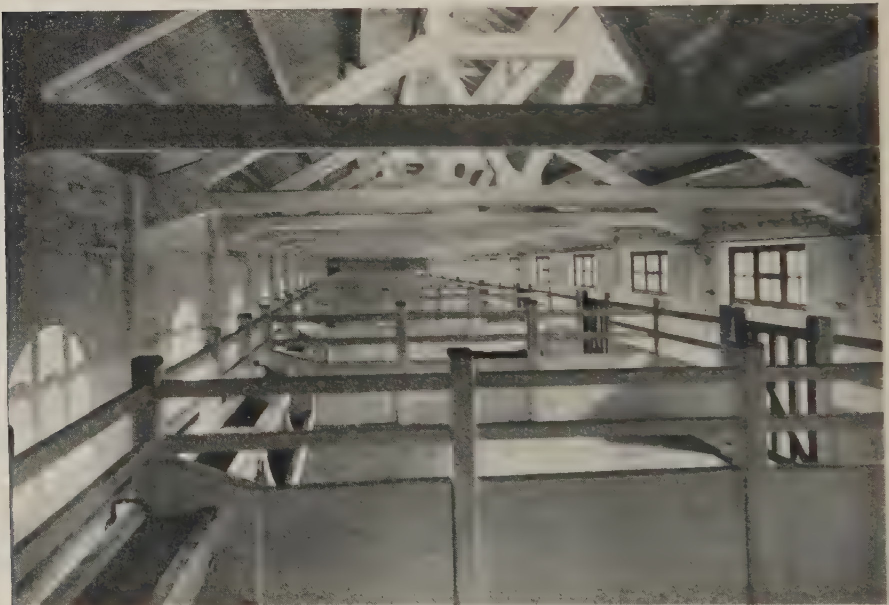


Fig. 559.—Concrete Meat Market, Birmingham.

able throughout the year; they never become quagmires which are quite unusable during wet seasons; and less tractive effort is at all times necessary, thus allowing the farmer to make fuller use of modern means of transport. In *Fig.* 557 is seen a typical concrete farm road, clean and well drained throughout the year; *Fig.* 558 is a concrete track through a piggery, with drainage channels at each side.

Silos

Farm silos may be constructed of cast *in situ* concrete, pre-cast concrete blocks or pre-cast concrete staves. The usual sizes range from 25 to 50 ft. in height and 10 to 20 ft. in internal diameter. The location of a silo is important; so far as possible it should be close to the cattle sheds and deliver straight into them. In order to facilitate the filling of the silo there should be a good road and ample space around its base.

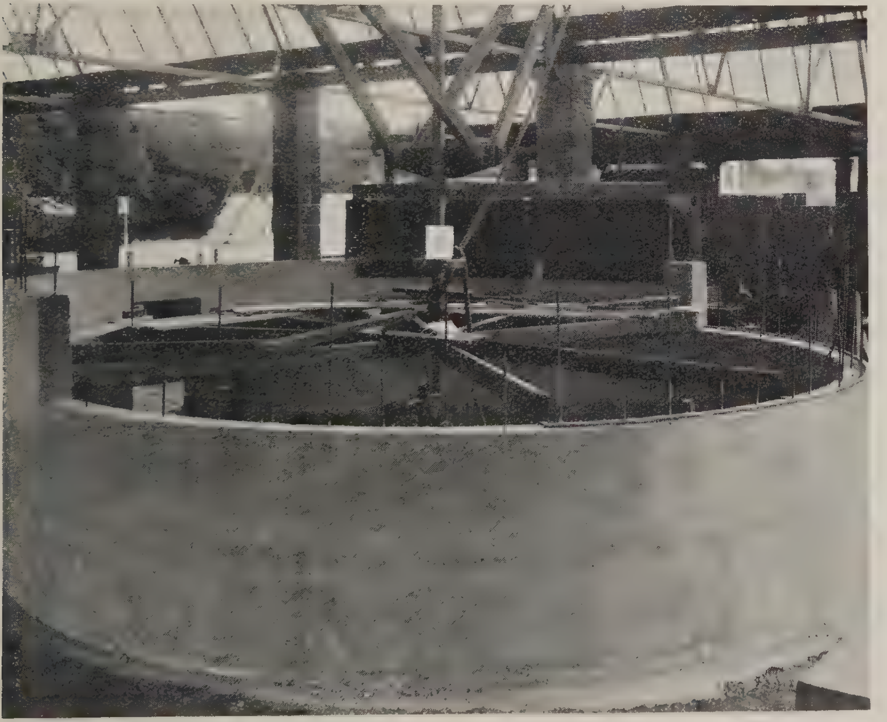


Fig. 560.—Concrete Silo Construction.

The lateral pressure of the ensilage must be resisted by the walls of the silo which consequently require reinforcement to resist the tensile stresses. Generally ½-in. bars are used (for walls of *in situ* silos) in the circumferential direction, the spacing varying from a minimum at the bottom to a maximum at the top. It is advisable not to space these bars more than 12 in. apart and to lap them for a length of sixty diameters. The laps should be staggered around the circumference. Vertical reinforcement, consisting of ⅜-in. bars at 2-ft. or 2-ft. 6-in. centres (*Fig.* 560) is necessary in all farm silos. The vertical and horizontal bars should be wired together with 16 S.W.G. soft iron wire at all their intersections.

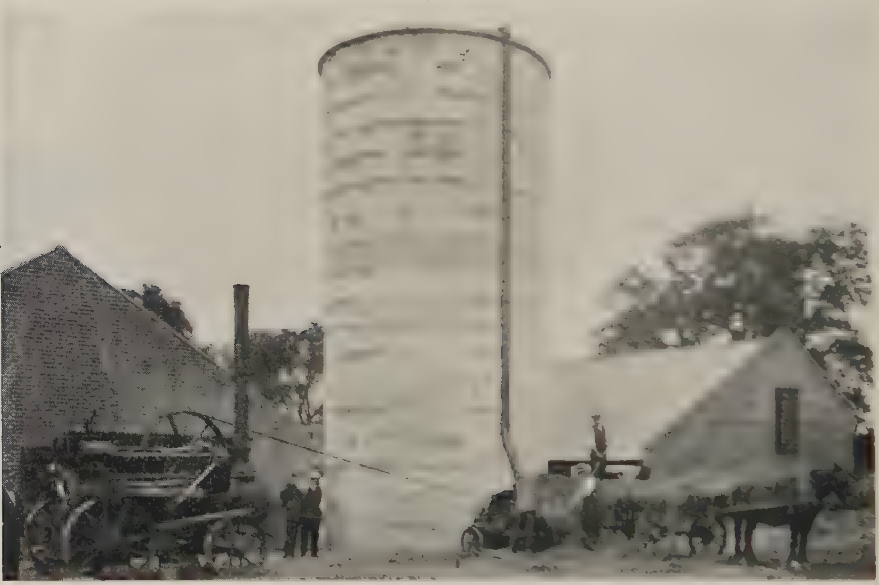


Fig. 561.—Concrete Silo in Norfolk.

Formwork for small silos such as are used on farms is best made as moving forms supported on a central post (see Part IV).

The concrete used in the walls should not be leaner than a 1 : 2 : 4 mix and a minimum thickness of 6 in. should be adopted for the wall. A 1 : 2½ : 5 mix may be used in the foundations and floor. As the total quantity of concrete in an average silo is small, it does not pay to use any more elaborate hoisting gear than a cathead or ginpole.

Fig. 562 shows a silo constructed with pre-cast blocks. To resist the tensile stresses circumferential steel bars must be buried in grooves in the blocks which are filled with mortar.

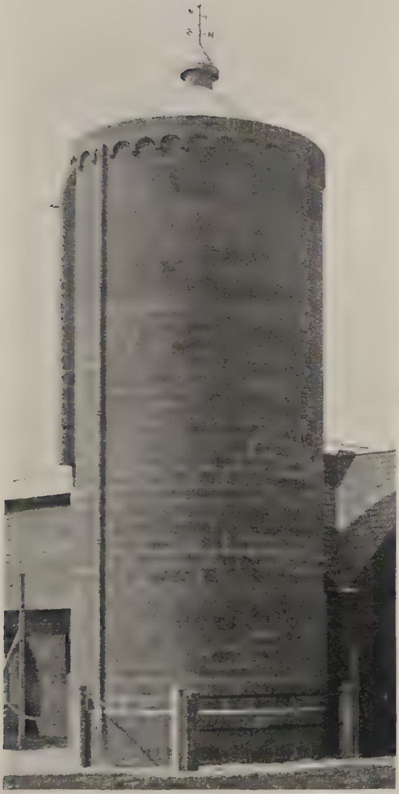


Fig. 562.—Concrete Block Silo.

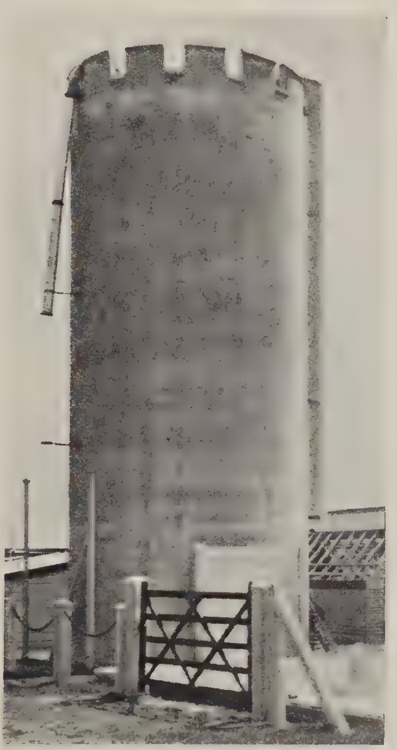


Fig. 563.—Concrete Silo.

A modern development of silo design is to use pre-cast concrete staves which are bound together with steel tie rods with adjustable couplings.

PART VII

CAST STONE

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CAST STONE

THE dividing line between what are known as "cast stone" and "concrete products" may roughly be defined as follows : Cast stone is a representation of natural stone, moulded to various shapes and with a good surface finish, which is equal in appearance and durability to natural stone after the latter has been cut and shaped by the mason ; concrete products are utilitarian units which have to compete with cheaper building materials such as brick and wood. Cast stone is generally made to an architect's design, and special moulds have as a rule to be made for every job. Concrete products are more or less standardised in shape and size, and may be made by mass production methods by machine or individual moulds may be used until they are worn out. In this volume cast stone and concrete products are dealt with in separate sections, although naturally some of the notes given here in connection with cast stone also relate to Part VIII which deals with concrete products.

Generally the principles of making ordinary concrete apply to the manufacture of cast stone, but extra care in the processes and workmanship is necessary due to the good quality and appearance required in this class of work. To afford ample time for moulding the cement should be slow-setting, and it should be rapid-hardening in order to allow quick release of moulds and rapid delivery. "Ferrocrete" Portland cement fulfils both these requirements.

Materials

The notes on quality and grading of aggregates in Parts I and II apply equally to aggregates for cast stone. As its name implies, "cast stone" is a reconstruction of natural stone, and crushed stone is generally used for aggregate. For certain purposes, however, sands are suitable, such as Leighton Buzzard sand for matching Portland stone, red sands for matching red stones, silica sands for matching granite, etc. Typical cast stones are shown in colour in Plates I, II and III, from which it will be seen that a perfect representation of natural stone is obtained.

The usual proportions are one part of Portland cement to three parts of aggregate. Too high a proportion of cement will cause crazing on the face of the stone, while too lean a mix will result in a weak stone that may be permeable. The size of the aggregate for the face should not exceed $\frac{1}{4}$ in. with any dust eliminated; larger aggregate is difficult to place in ornamental moulds, and is also more difficult to tool or grind to a good surface.

For all the lighter shades of stone "Snowcrete" white Portland cement should be used. Obviously it is impossible to obtain a white stone with grey cement, while the grey shade of ordinary cement makes it difficult to match the lighter and medium colour stones, although in some cases a good result may be obtained with mixtures of white and grey cements. It is sound practice to use "Snowcrete" for all cast stone work.

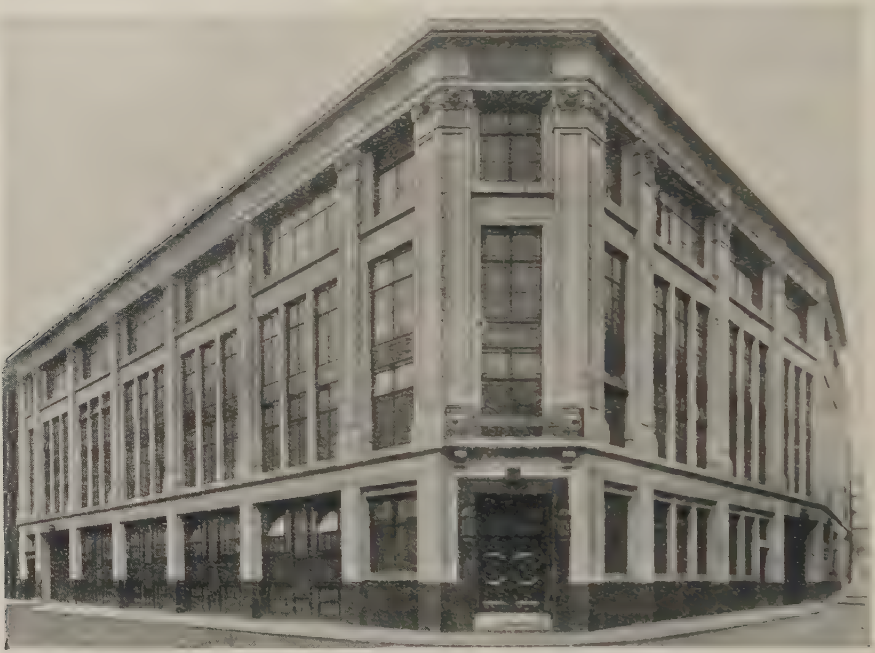


Fig. 564.—Cast Stone Elevations, Northcliffe House, London.

When coloured stone is to be matched, the cement should be coloured to the same shade as the natural stone. Ready-coloured Portland cements (see Part III) are on the market for this purpose, and cement manufacturers specialising in coloured cements will make up any colour desired. The cement may also be coloured by the cast stone manufacturer by the addition of mineral oxides. These have a slight weakening effect on the concrete, and should not be used in proportions exceeding 15 per cent. by volume of the cement content; a smaller proportion, say, 8 per cent., is desirable, and it will often be found that a desired shade can be obtained by the use of smaller proportions of darker shades than if a lighter shade were used.

When matching colours it is advisable to mix a small batch, keeping a careful record of the quantities of materials and colour used, and make a trial slab so that the shade may be noted after the slab has dried out. If this is not the exact shade desired, the proportion of colour should be varied in other trial slabs until the desired shade is obtained. Further information on colouring, together with the necessary proportions of admixtures to

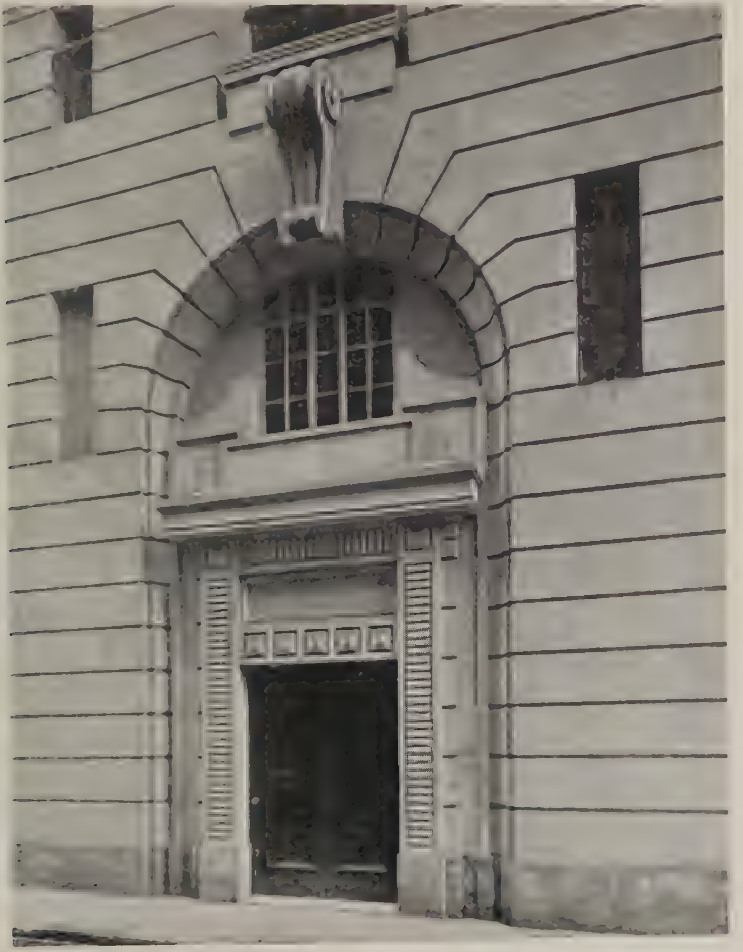


Fig. 565.—Cast Stone at the Conservative Club Building, London.

produce different colours and shades, is given in Part III, "Surface Treatment."

Matching Natural Stone. -Suitable proportions for matching various natural stones follow :

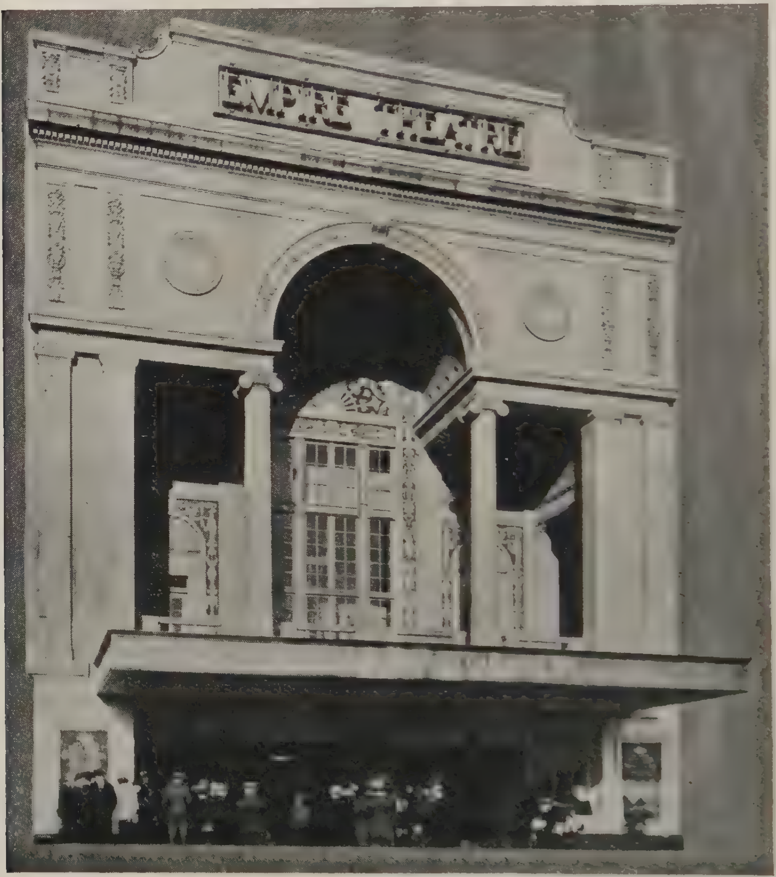


Fig. 566.--Cast Stone Elevation, Empire Theatre, Leicester Square.

Formulæ for Making Cast Stone

Cast Portland Stone—

1½ parts of Portland stone ⅜ in. to ⅛ in.
1½ parts of Portland stone ⅛ in. down.
1 part of "Snowcrete" white cement.

Alternative Formula—

3 parts of Portland stone $\frac{1}{8}$ in. down, dust in.
1 part of " Ferrocrete " rapid-hardening Portland cement.

Alternative Formula—

3 parts of Portland stone $\frac{1}{8}$ in.
1 part of a mixture of 80 per cent. " Ferrocrete " and 20 per cent. " Snowcrete " white cement.

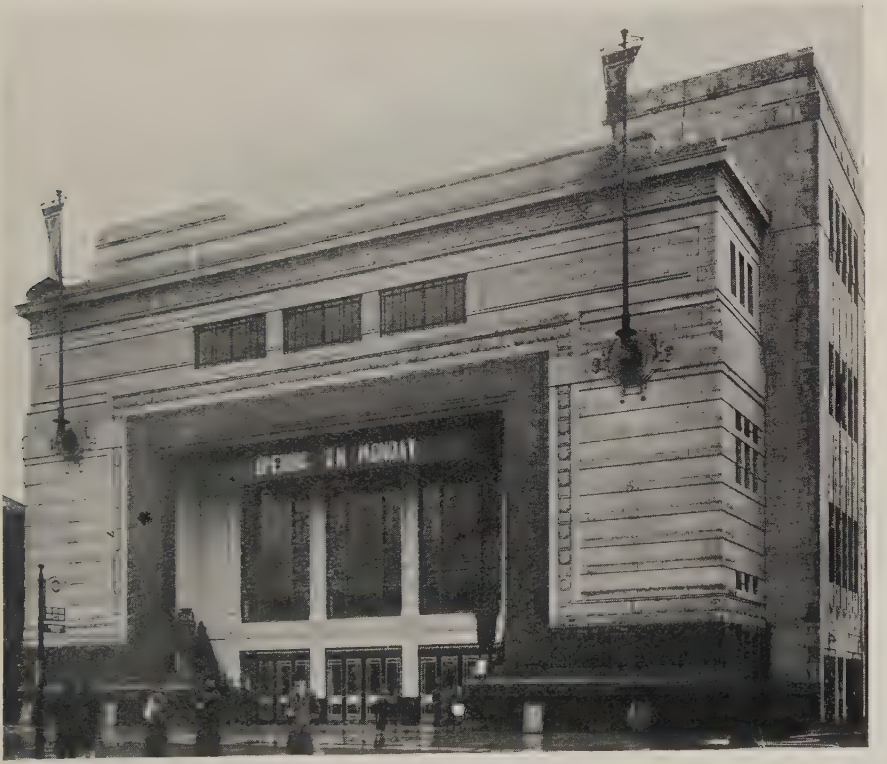


Fig. 567.—Cast Stone Elevation, Kensington Kinema, London.

Cast Red Sandstone—

3 parts of red sandstone.
1 part of " Colorcrete " (red).

Alternative Formula—

3 parts of crushed red sandstone $\frac{1}{8}$ in. down.
1 part of a mixture of 50 per cent. " Ferrocrete " and 50 per cent. of " Snowcrete " white cement, plus 5 per cent. of red oxide.

Cast Dark Mansfield Stone—

3 parts of Mansfield stone through an $\frac{1}{8}$-in. sieve.
1 part of "Colorcrete" (red).

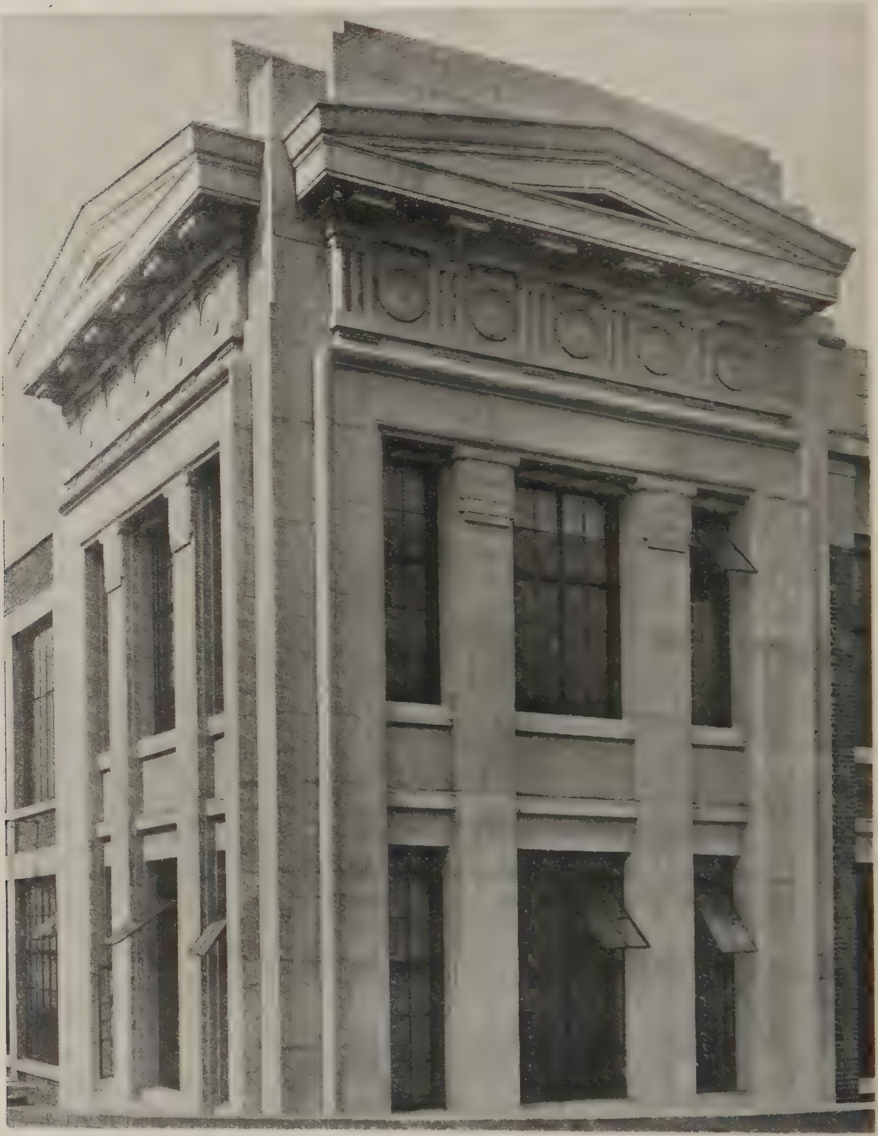


Fig. 568.—Cast Stone on a Factory Building at Nottingham.

Cast Granite—

3 parts of china clay sand
1 part of "Ferrocrete."

Cast Light Mansfield Stone—

4 parts of light Mansfield stone through a $\frac{1}{4}$-in. sieve.
1 part of coloured cement 50 P 5. (This mixture is suitable for sand moulding.)

Cast Ham Hill Stone—

3 parts of Ham Hill stone through a $\frac{1}{4}$-in. sieve.
1 part of "Colorcrete" (buff).

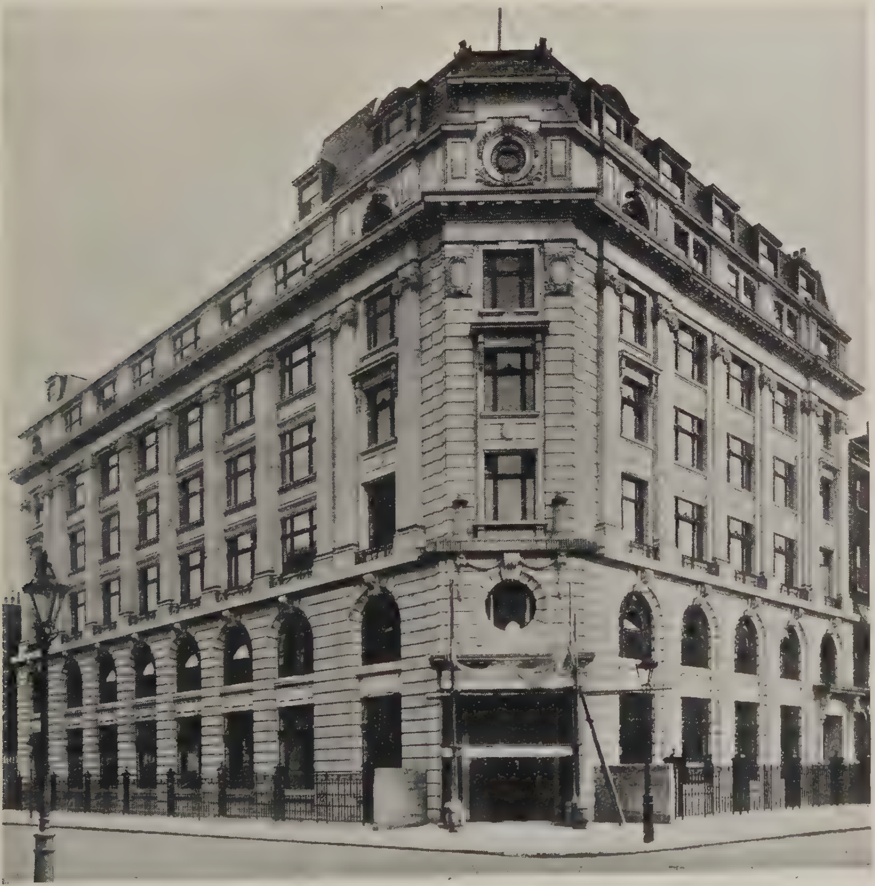


Fig. 569.—Cast Stone Elevation, Maypole House, Finsbury Square, London.

Cast Hopton Wood Stone—

4 parts of a mixture of
  10 per cent. of Hopton Wood stone $\frac{1}{8}$ in. to $\frac{1}{16}$ in.
  90 per cent. of Hopton Wood stone through a 20 × 20 sieve.
1 part of "Snowcrete" white cement. (This surface should be rubbed to a polish with carborundum.)

Cast Rhondda Valley Stone—

3 parts of dark silver sand.
1 part of "Ferrocrete."

Cast Yellow Sandstone—

3 parts of crushed yellow sandstone.
1 part of "Snowcrete" white cement, plus 1 per cent. of yellow ochre.

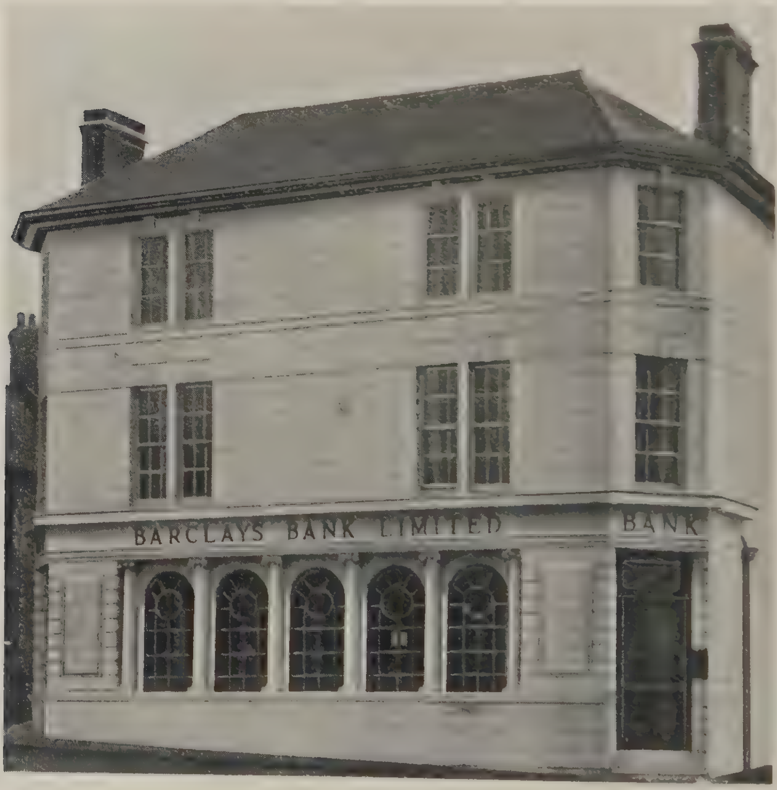


Fig. 570.—Cast Stone on a Bank at Bude.

Alternative Formula—

3 parts of yellow sandstone.
1 part of "Ferrocrete" plus 3 per cent. of brown ochre.

Cast Grey Limestone—

3 parts of grey limestone.
1 part of a mixture of 50 per cent. of "Ferrocrete" and 50 per cent. of "Snowcrete" white cement.

Cast Kentish Ragstone—

3 parts of Kentish ragstone $\frac{1}{8}$ in. down.
1 part of "Ferrocrete."

Cast Conisboro' Cliff Stone—

3 parts of yellow limestone $\frac{1}{8}$ in. down.
1 part of "Snowcrete" white cement plus 2 per cent. of yellow ochre.

Cast White Sandstone—

3 parts of white sandstone through a 20 × 20 sieve.
1 part of "Snowcrete" white cement.

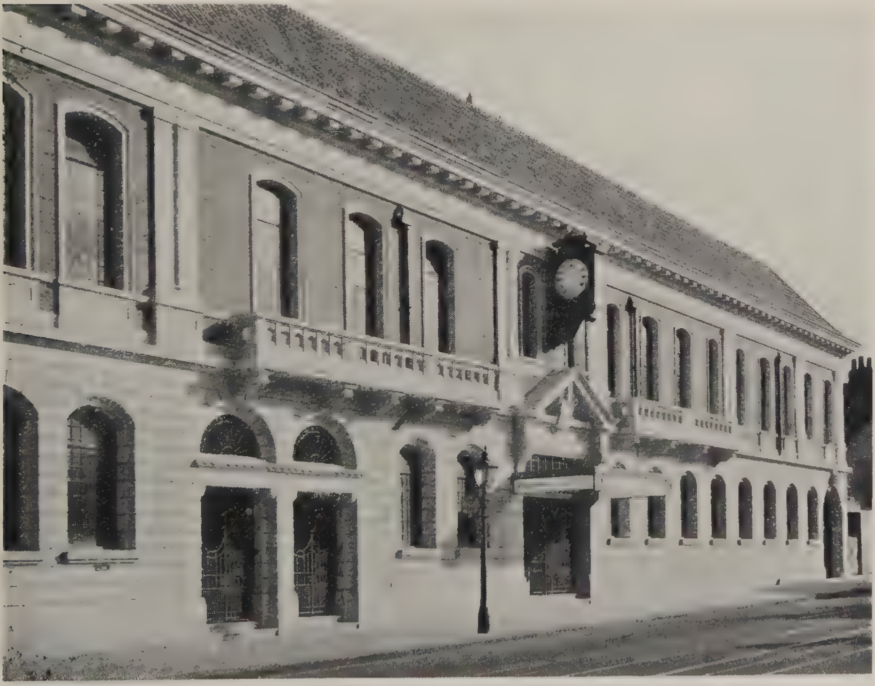


Fig. 571.—Wandsworth Town Hall: Cast Stone Facings.

Cast Marsden Quarry Stone—

3 parts of stone through an $\frac{1}{8}$-in. sieve.
1 part of "Ferrocrete" plus 2 per cent. of yellow ochre.

Cast Crowborough Stone—

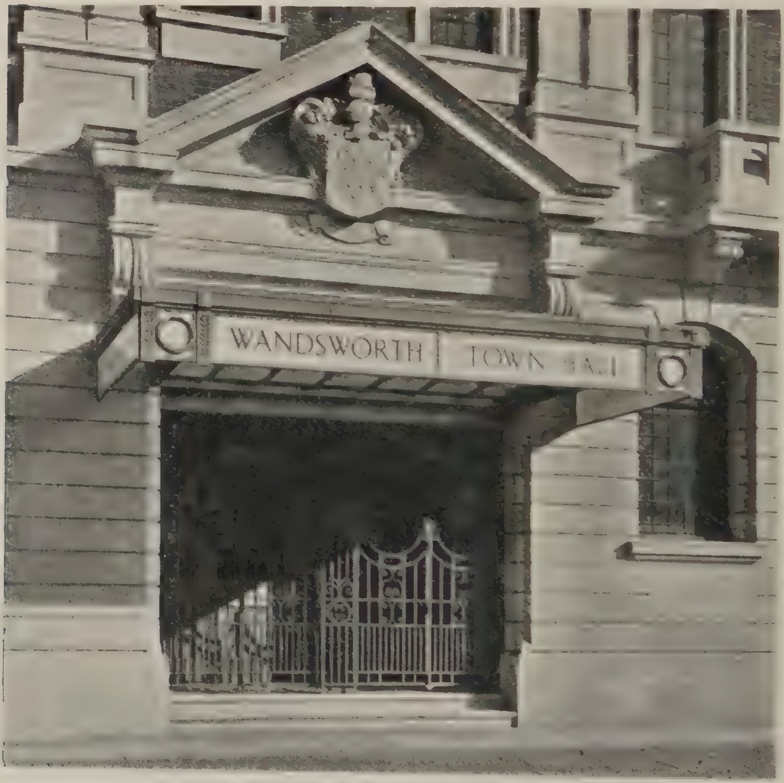
3 parts of crushed Crowborough stone through a 20 × 20 sieve.
1 part of a mixture of 60 per cent. of "Snowcrete" white cement and 40 per cent. of "Ferrocrete," plus 4 per cent. yellow ochre.

Cast Doulting Stone—

3 parts of Doulting stone $\frac{1}{8}$ in. down.
1 part of a mixture of 80 per cent. "Snowcrete" white cement and 20 per cent. of "Ferrocrete," plus 1 per cent. of yellow ochre.

Cast White Freestone—

4 parts of freestone crushed through a 20 × 20 sieve.
1 part of "Snowcrete" white cement.



572.—Cast Stone Entrance Detail, Wandsworth Town Hall.

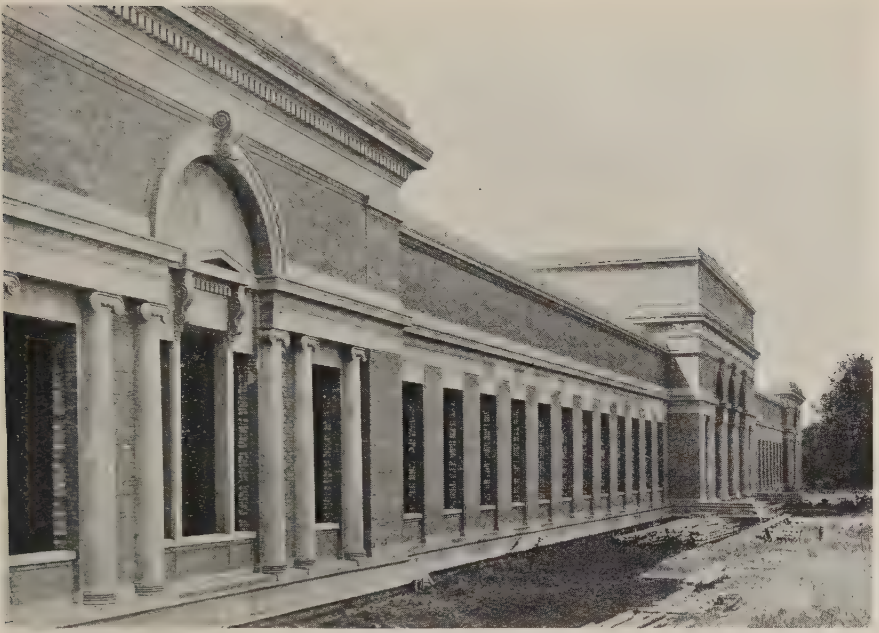


Fig. 573.—Pre-Cast Concrete Factory at Baldock, Herts.

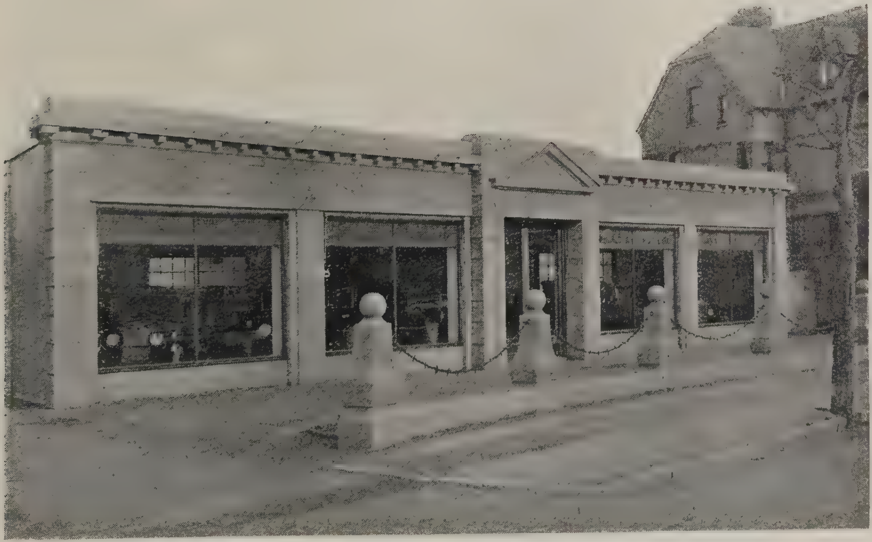


Fig. 574.—Showroom for Cars in Cast Ham Hill Stone.

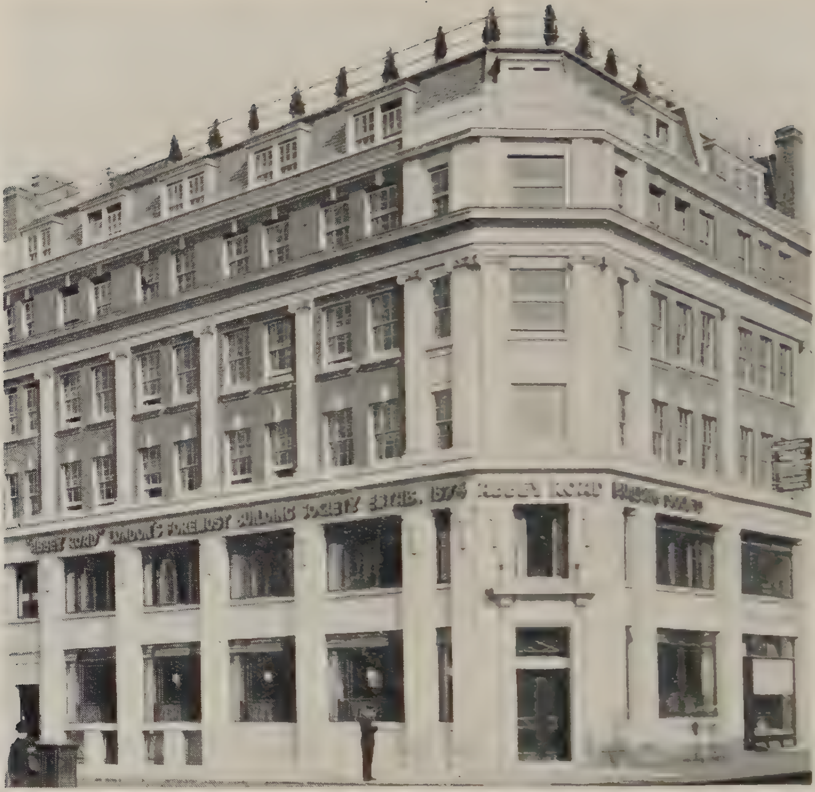

"ABBEY ROAD" LONDON'S FOREMOST BUILDING SOCIETY ESTAB. 1874

Fig. 575.—Cast Stone on New Premises of Abbey Road Building Society.

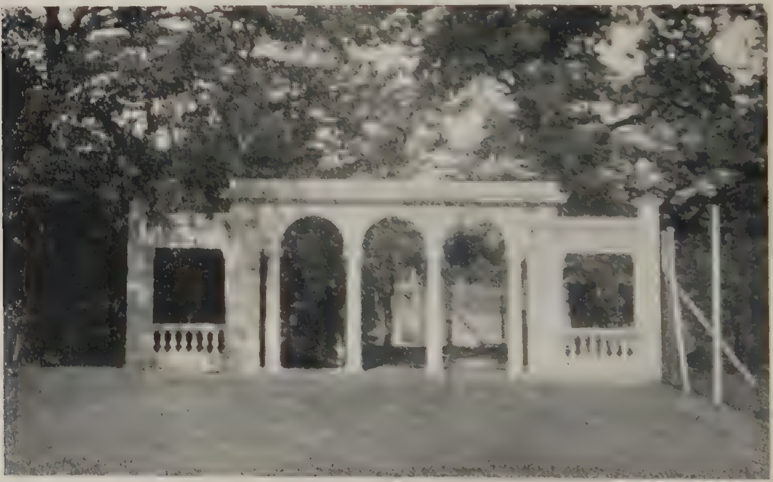


Fig. 576.—Cast Stone Screen at a Sports Ground.

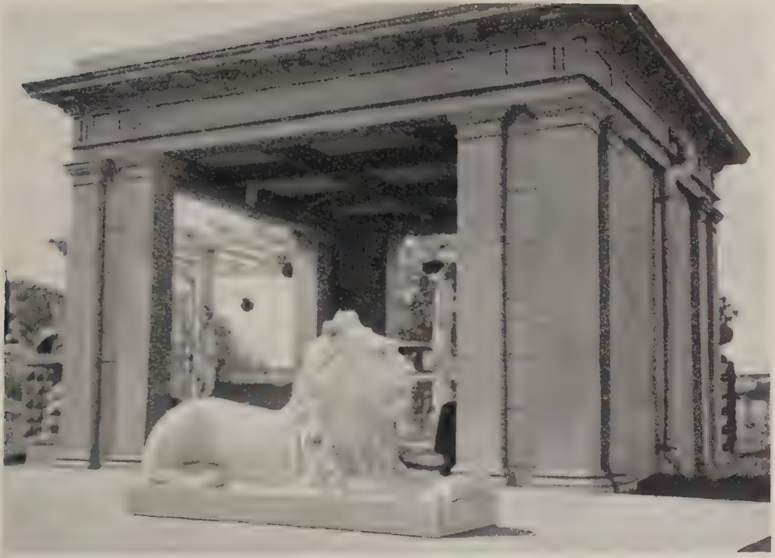


Fig. 577.—Cast Stone Sculptured Lion.

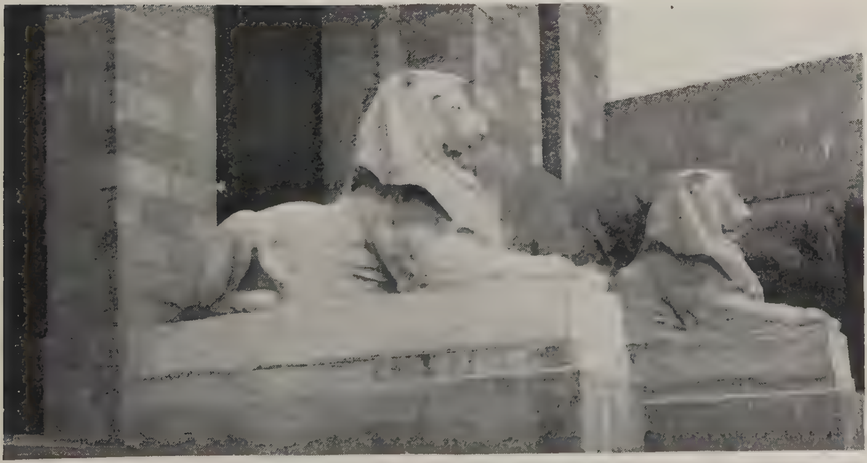


Fig. 578.—Cast Stone at British Empire Exhibition.

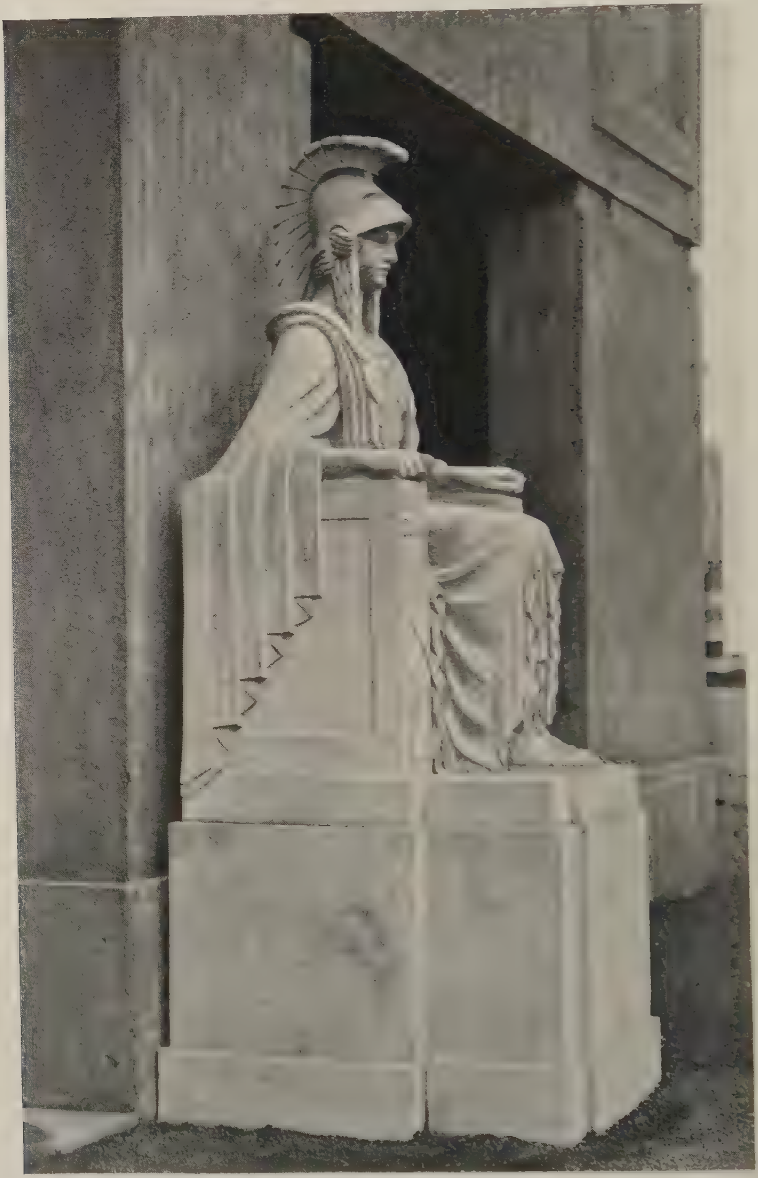


Fig. 579.—Cast Stone Statue.

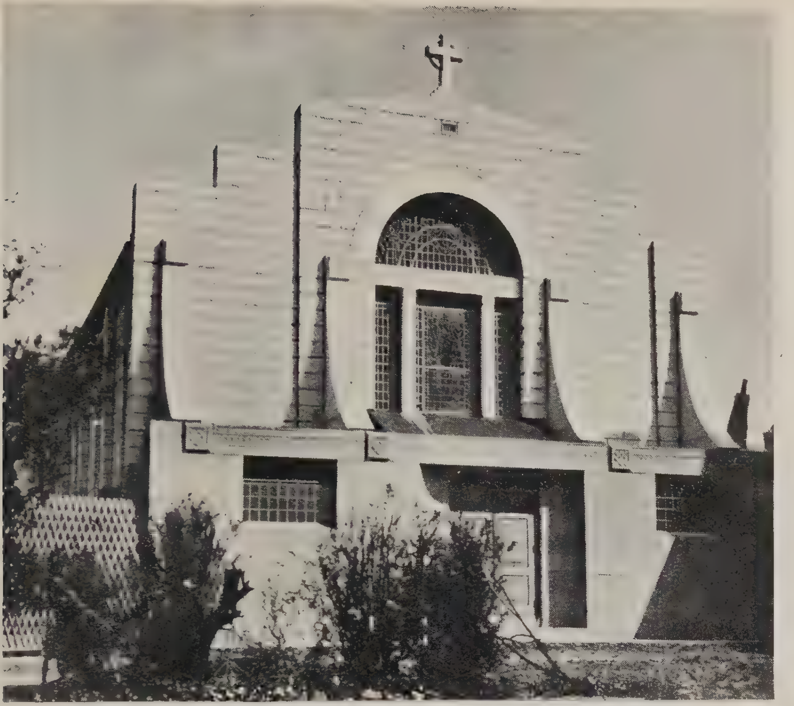


Fig. 580.—Cast Stone Church at Ilminster.

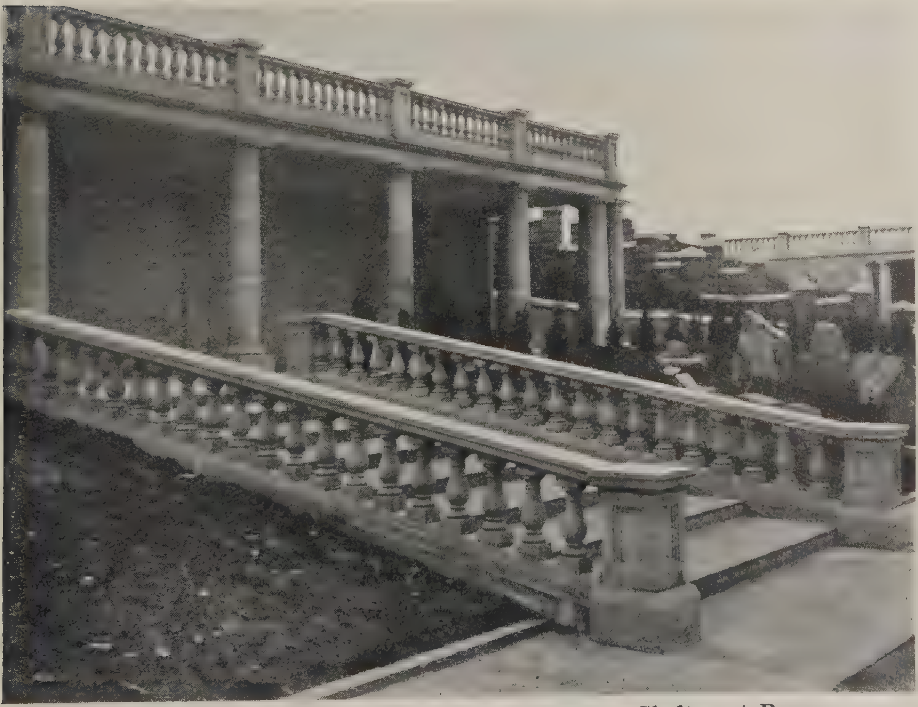


Fig. 581.—Cast Stone and Reinforced Concrete Shelter at Barry.

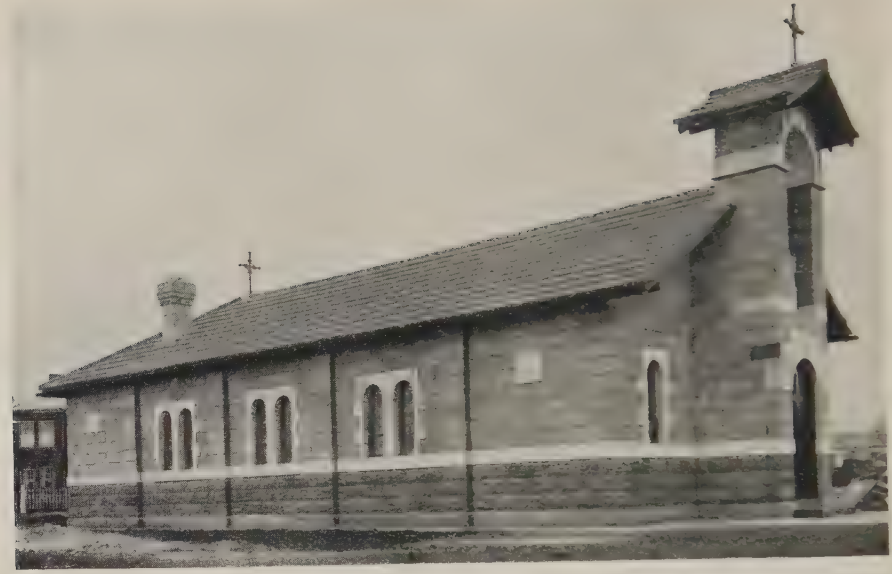


Fig. 582.—Cast Stone Chapel at Totton, near Southampton.

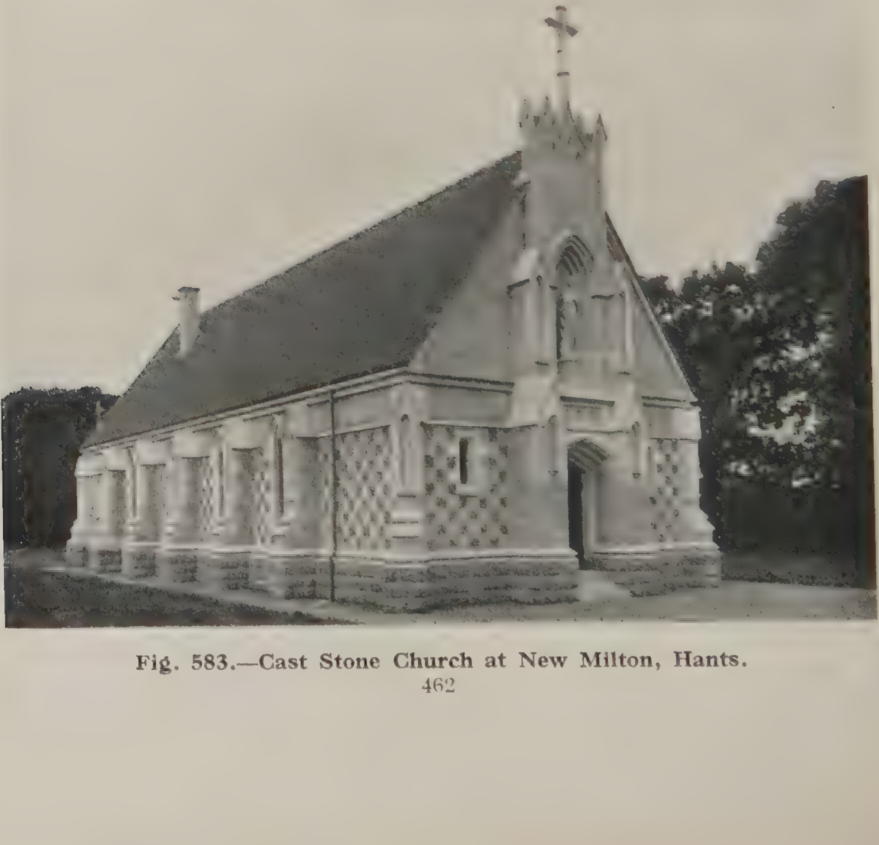


Fig. 583.—Cast Stone Church at New Milton, Hants.

Cast Ketton Oolite Stone—

4 parts of Ketton oolite sand $\frac{1}{16}$ in. down.
1 part of coloured cement ref. 80 W $2\frac{1}{2}$.

Cast Sussex Ironstone—

3 parts of crushed ironstone $\frac{1}{8}$ in. down.
1 part of "Ferrocrete" plus 3 per cent. of brown ochre.

All these surfaces, with the exception of cast Hopton Wood stone, can be tooled, rubbed to an ashlar face, or wet scrubbed when 24 hours old.

As natural stone varies in colour these proportions can only be tentative; they will produce concrete the same colour as average stone, but to match exactly any particular sample it may be necessary to vary the proportion of colour or the proportion of white or grey Portland cement.

Fig. 584.—Church at New Milton, Hants.

Tooling and Polishing.—Cast stone may be surface treated by any of the methods of finishing natural stone. If it is to be polished it may be first necessary to fill any small holes on the surface, and for this purpose a mortar is made of the same materials used for the stone and this is filled into the holes with a trowel.

If the stone is to be polished it is advisable to work it as soon as possible after casting, that is, while the concrete is still "green" but hard enough

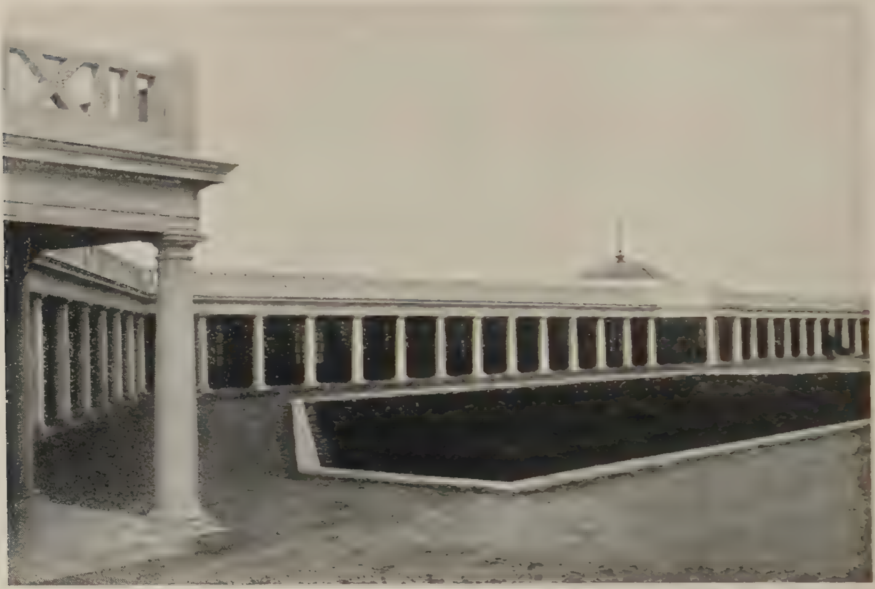


Fig. 585.—Cast Stone Colonnade at Sandbanks Pavilion, Poole.

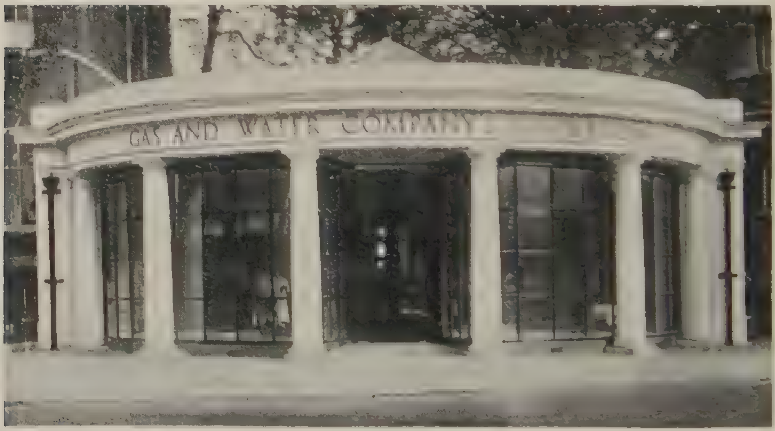

GAS AND WATER COMPANY

Fig. 586.—Cast Stone Front to Show Rooms.

to withstand rubbing without damaging the surface. With rapid-hardening cement this may often be done within 24 hours, but 3 or 4 days' curing are generally necessary with ordinary Portland cement. Polishing is effected either with a polishing machine or by using carborundum stone. During rubbing the best results are obtained by using water freely, washing off the water as it gets thick with the dust rubbed from the surface. A polished surface is shown in Part III.

Cast stone may also be tooled with chisels in the same way as natural stone. If this is done it is not necessary to fill small holes in the surface, as the chisel will take off the top to a thickness of ⅛ in. or so. Typical tooled finishes are shown in Part III.

Exposed aggregate treatment consists of the removal of the surface film of cement so that the aggregate is revealed, as described in Part III, "Surface Treatment."

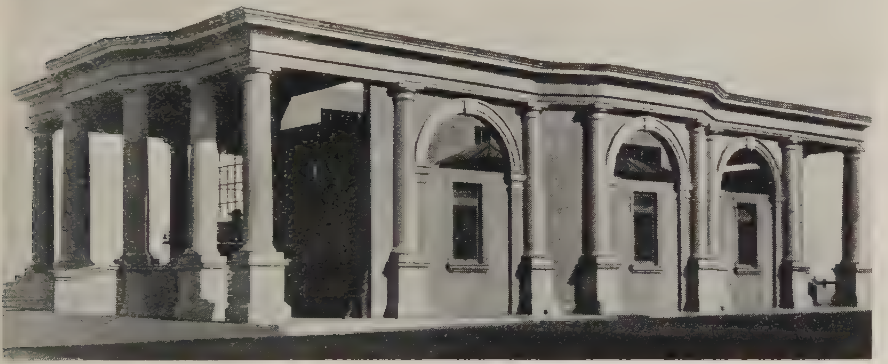


Fig. 587.—Cast Stone Shelter at Herne Bay.

Mixing and Placing.—Unless mechanical means of consolidation are available, i.e., vibration or mechanical tamping, the concrete for cast stone work should not be "dry" or "semi-dry" for the principal reasons that a harsh dry mix will be difficult to force into the detail and corners of the mould, and that it will probably result in a weak and porous stone. When rigid moulds are used the best consistency is that known as "plastic," that is, a mix which, while not "sloppy," will flow into all the detail of the mould. Although some loss of strength may occur if too much water is used, even lower strengths would be obtained from the use of too little water. Also, the difficulty of compacting a harsh mix may result in the presence of holes on the face of the stone, due to the absence of density caused by insufficient lubrication of the mass preventing the smaller particles from flowing into position between the larger stones. The unsatisfactory surfaces resulting from the use of insufficient water are expensive to make good,

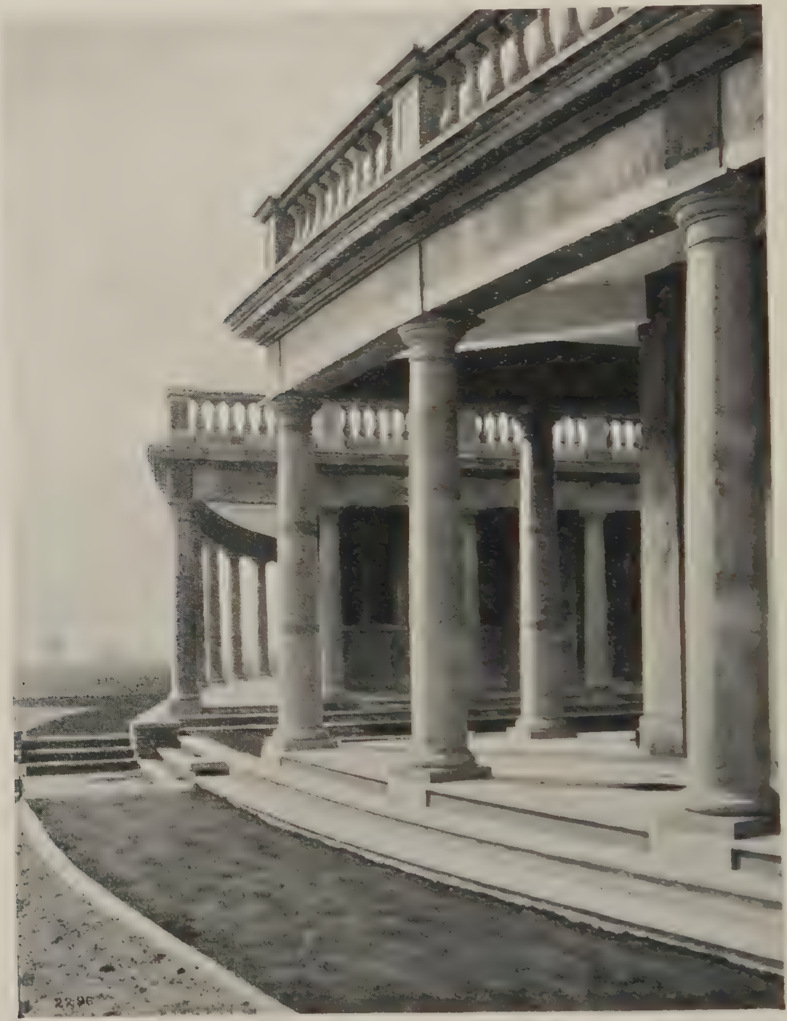


Fig. 588.—Cast Stone Colonnade at Eaton Park, Norwich.

and should be avoided if possible. Prolonged mixing, say, ten minutes in the machine, helps to produce a plastic mix with a minimum of water, as also does good grading of the aggregates. Generally, however, a wet mix is more liable to surface pockets than a drier mix.

MOULDS

Wood is the material principally used for moulds, owing to its cheapness and the ease with which it may be worked. Plaster, metal, sand, gelatine, and other materials are also used, as described later. Whatever the material,

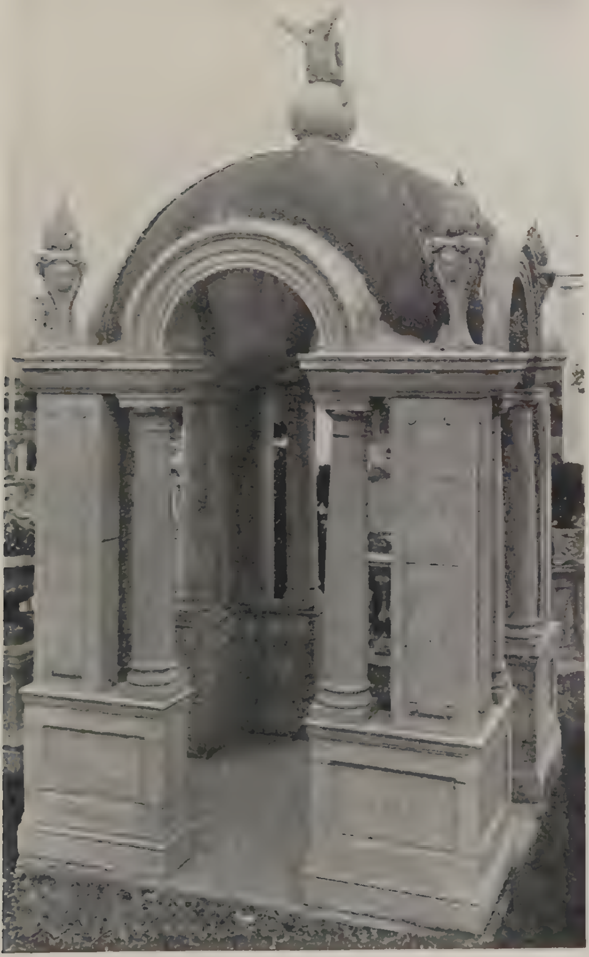


Fig. 589.—Cast Stone Pavilion.

moulds must be carefully and strongly made ; time spent on moulds to make them as perfect as possible is time well spent. Imperfection in moulds will result in faulty stones, with consequent trouble and expense in "truing" them or making good the surfaces.

Wood Moulds.—Wood moulds, typical examples of which are shown in *Figs.* 592–3, 597–8, and 602–5, should be made by skilled carpenters. Generally they are made from drawings, and if they are at all large, or intricate in outline, they should first be set out on the floor on a board. Deal is the wood most frequently used, and is satisfactory for practically all classes of work; it should, of course, be free from twist and knots that are likely to fall out. The chief point to remember in mould making is that it must be possible to strip the mould entirely from the outside, so that no parts that have to be removed should be fixed from the inside. Screws are to be preferred to nails as they can be removed more easily and without damaging the mould. Joiners' clamps are also often used owing to the ease with which they may be removed to release the mould.

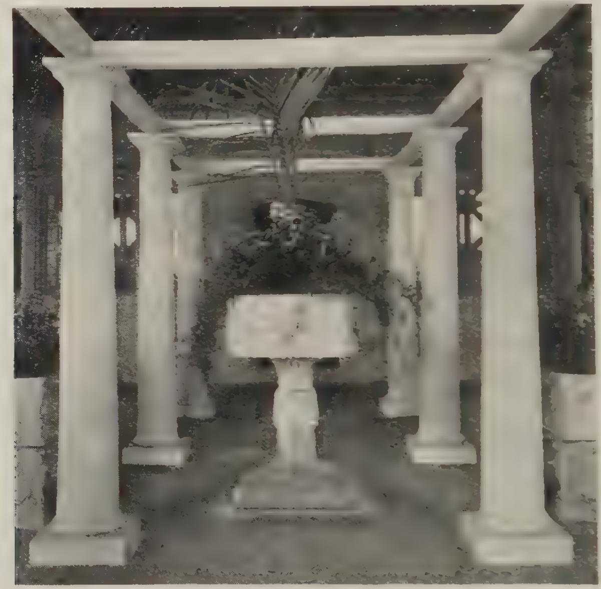


Fig. 590.—Cast Stone Columns and Vase.

To avoid twisting of the wood when wet, moulds should be made of stout timber, usually from 1 in. to 2 in. thick. In the case of exceptionally large moulds the sides should be stiffened with battens, or by chocks fixed to the baseboard. Bases should always have battens beneath them (see *Fig.* 592) so that the fingers may be inserted beneath when lifting or turning the mould.

Wherever possible the stones should be made face down, as a better surface will result from moulding on a rigid bottom than if they were made face-up, as in the latter case the trowelling or screeding necessary to produce a true surface will cause laitance, or a film of neat cement, to rise to the top. Ramming of the face can be done more thoroughly if it is at the bottom of the mould. Also, in the face-up process, in the case of stones such as cornices it would be impossible to form the outline except by the use of templates, which may be unsuitable because of the dry mix that would be necessary to allow of this method and also because of the impossibility of proper tamping.

Fig. 591.—**Cast Stone Pergola.**

In its simplest form a mould is a rectangular box without a top. This is shown in *Fig.* 592, in which the sides (*b*) are shown fixed to a base (*a*). The sides are screwed to the base from the underside, and held the correct distance apart at the top by wood distance pieces (*g*); the latter are fixed to blocks (*f*) mounted on the top of the sides to allow a trowel or screed to pass under them. The ends (*c*) are held in position by the stops (*d*) and are not fixed, the pressure of the concrete being sufficient to hold them in position. The stops (*d*) are screwed to the sides. To strip such a mould after the concrete has hardened, remove the distance-pieces from the top and turn the mould completely over; take out the screws holding the sides and remove the base; the sides and ends will then come away.

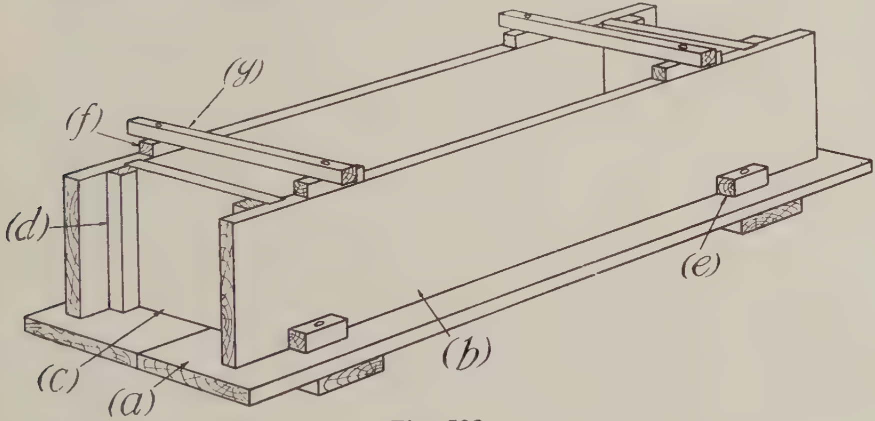


Fig. 592.

For the production of such stones as sills, heads, lintels, etc., in this type of mould, all that is necessary is to place shaped pieces in the bottom.

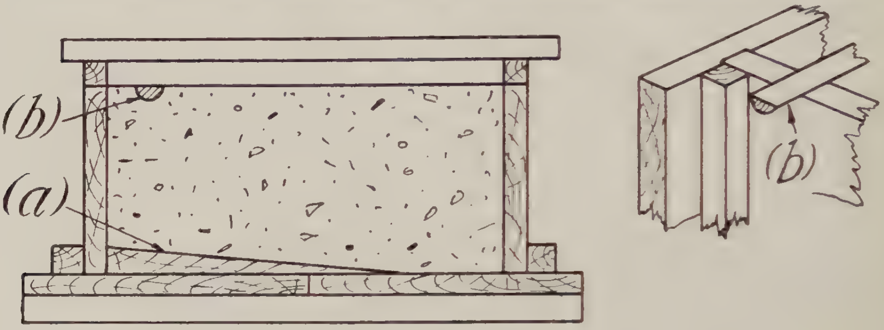


Fig. 593.

or bottom and one side, to give the desired shape to the face. To demonstrate this in its simplest form a sketch is given in *Fig.* 593 showing a cross-section through such a mould arranged for the manufacture of a simple type of sill, with a slope on part of the face; as will be seen, all that is necessary is to place a shaped piece of wood (*a*) in the bottom cut to the desired slope of the top of the sill. A throating on the underside of the sill is formed by pressing a rod (*b*) into the concrete, and resting in grooves cut in the ends of the mould, after the mould has been filled, shown in the detail sketch.

Fig. 594.—Cast Stone Doorway.

If the stone is to be moulded on two sides, shaped pieces are placed in the bottom and in one side. This is shown in *Fig.* 597, a section through a mould for a door head with a sloping top and moulded face. In this case a piece of moulding (*a*) corresponding to the outline of the face is placed in the bottom of the mould, and a tapered piece (*c*) to give the sloping top fitted against the inner face of the side of the mould; the former should be screwed to the base and one side, and the latter to the opposite side. If the head is a long one it is desirable to fix these blocking pieces at several points to prevent twisting when wet. If a water-drip is required on the underside, this is obtainable by fixing a strip (*b*) to the corresponding mould side.

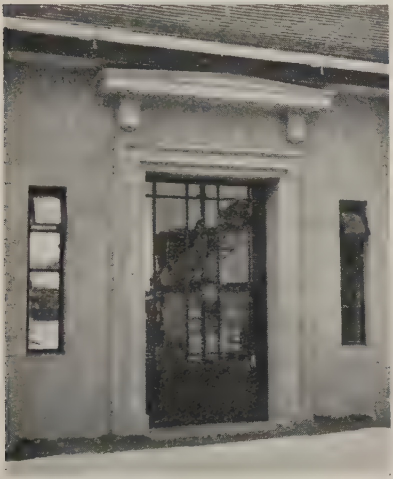


Fig. 595.—Cast Stone Door.

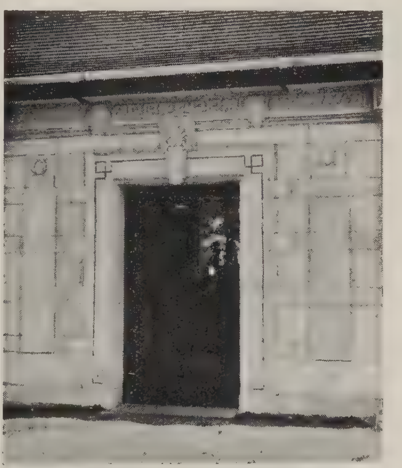


Fig. 596.—Cast Stone Door.

These few diagrams demonstrate the principle of wood mould-making, but a few further general notes may be useful. Before the mould is used it is desirable to soak it in water for twelve hours or so in order to see whether it will get out of shape when wet; if this does happen the mould can be trued up before use, and thus avoid the far more difficult task of altering the stone when it is made. Also to allow for the inevitable swelling of the wood, the joints in the mould should not be too tight. In the case of moulds for large cornices and suchlike, the blocks to form the face may be built up if desired of several pieces, as is shown in *Fig.* 598; the different pieces may be screwed together to form one block when placed in the mould.

Of whatever the mould be made, it is important to make sure that all parts will come away. Reference to *Fig.* 598 will explain this point. It will be seen in a cornice of this shape that if the pieces (*a*) and (*b*) were made as one it would be difficult to get the stone out without damaging either the stone or the mould. To obviate this it is better to make up the moulding of separate pieces; in this case four pieces are suggested. The strip (*b*) should be lightly nailed from the top to the centre piece of moulding; this will hold it in position while the concrete is placed. This sketch shows the stone made sideface, the sloping part of the top being formed by a screed running on the sloping tops of the ends of the mould. To strip this mould, remove the distance-piece from the top, turn the whole upside down and remove the base followed by the sides and ends. The moulding can then be taken away from the face of the stone; the centre piece (*a*) bringing the strip (*b*) with it.

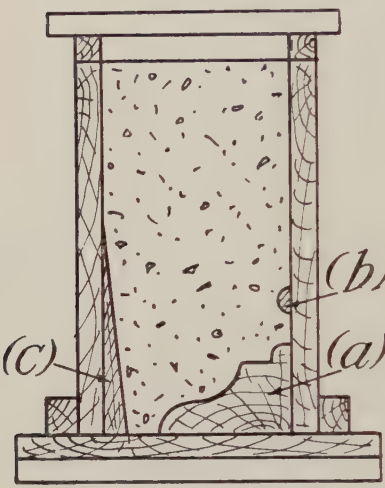


Fig. 597.

If a special face mixture is required this is mixed separately and either placed on top of the core if the stone is made face up or in the bottom of the mould if the stone is being made face down; the latter method is to be preferred resulting in a better bond between the two mixes. Special faces are generally from ¾ in. to 1½ in. thick according to the size of the stone. The practice in face-down manufacture is first to place the desired thickness of the special face mix in the bottom of the mould and then fill with the gravel-concrete core. If the special mix is required on one or both sides of the stone as well as on the face, the special mix is first placed on the bottom of the mould and for a few inches up the side, the consistency being such that it will stand up as placed; the core is then filled in to the

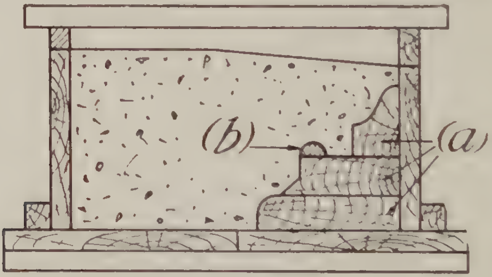


Fig. 598.

level of the face mix, and the face mix and core thus placed in layers until the top of the mould is reached.

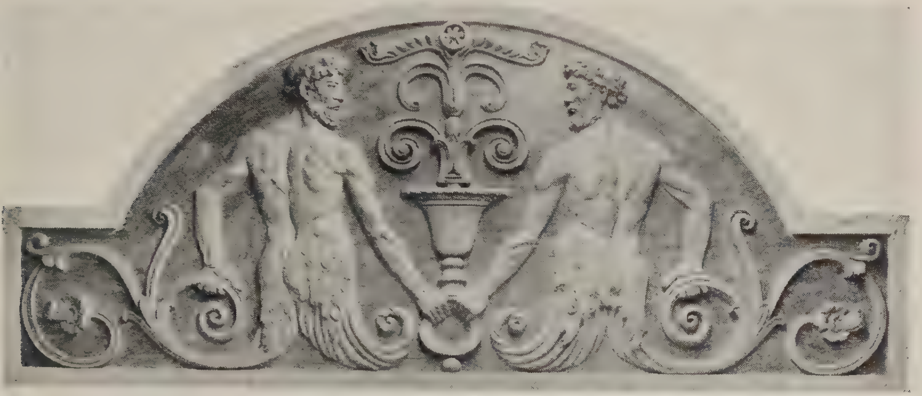


Fig. 599.—Cast Stone Decorative Panel.

Cores.—The principle of forming hollow cores in concrete units is shown diagrammatically in *Figs.* 602 and 603. If the hollow core may be tapered, as is generally the case when the core is only formed to lighten the weight of the unit, a simple method is to insert a tapered piece of wood (*a*) in the mould as is shown in *Fig.* 602. The taper-piece is held in position

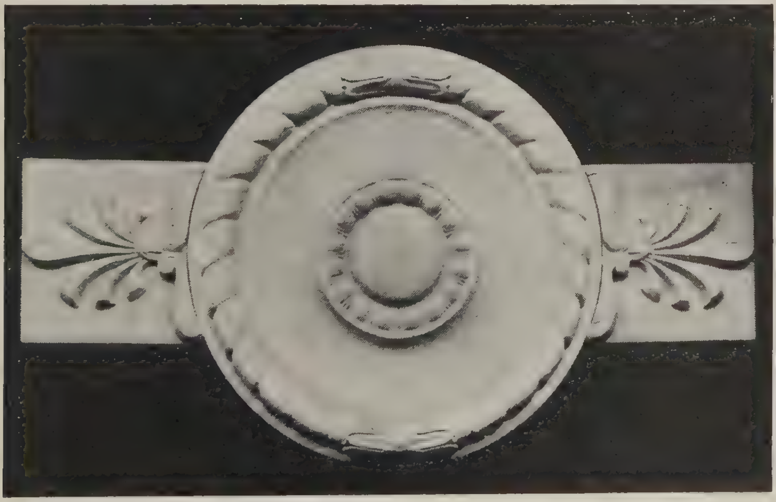


Fig. 600.—Architectural Detail in Cast Stone.

by fitting it over a wood peg (*b*) fixed to the mould-base and nailing or screwing it to the distance piece (*c*) at the top. If only one or two units are required it is simpler to nail or screw the taper-piece to the mould-base as well as at the top, driving the nail or screw from the underside. To strip the mould, take away the distance-piece and the sides of the mould and turn the product on its side; the base can then be taken away, and the core removed by knocking it through.

If it is not permissible to use a tapered core, the usual method (*Fig.* 603) is to form the core of two pieces (*a*, *a*) cross-cut in the shape of folding wedges. These core pieces are fixed at top and bottom in the same way as previously described for tapered cores, and removed in the same way except that the pieces are knocked out in opposite directions. These principles may be used for practically any shape of core met with in practice.

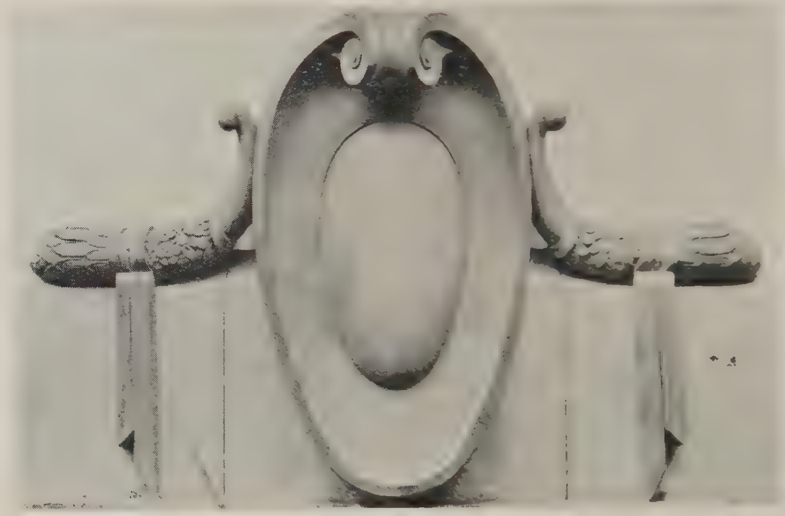


Fig. 601.—Cast Stone Architectural Detail.

Trough-shape products are made as shown in *Figs.* 604 and 605. As will be seen, they are made upside down. The construction of the outer mould follows usual practice. If the inner sides of the trough may be tapered (see *Fig.* 604) the mould is simplified, all that is necessary being two sides (*a*, *a*) and a top (*b*) supported to form the core. This core must be rigidly supported in position, by blocks (*d*, *d*) fixed to the base and boards (*c*) cut to shape.

A method of making troughs when the inner sides must be rectangular is shown in *Fig.* 605. In this case the core would be very difficult to release it made in three pieces only, as in *Fig.* 604, so it is preferable to make the top of the core in more than one piece. The method suggested is to form

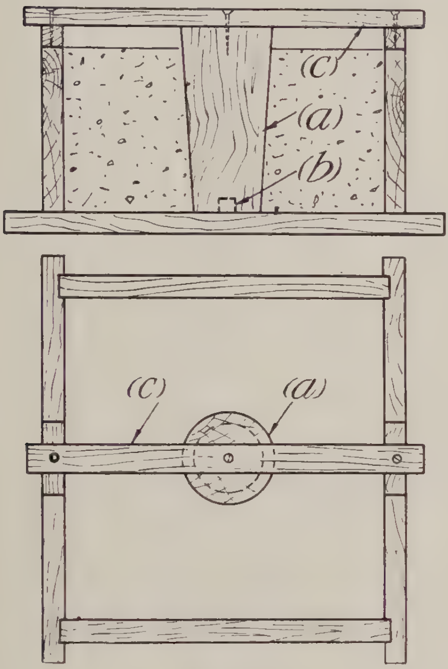


Fig. 602.

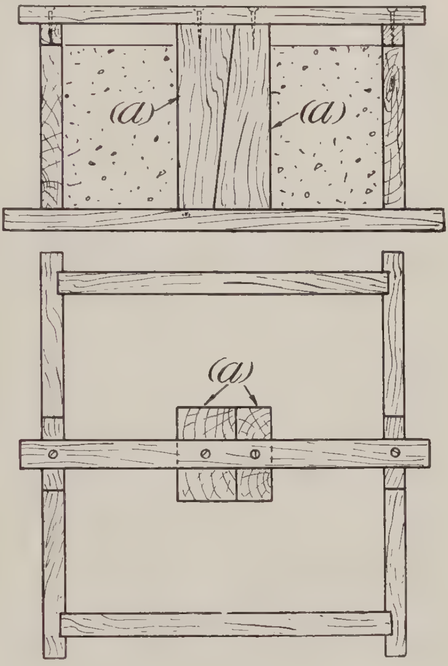


Fig. 603.

the top of the core in three pieces (*b, c, b, Fig.* 605). The three boards should be well tapered to allow for easy withdrawal, and held in position

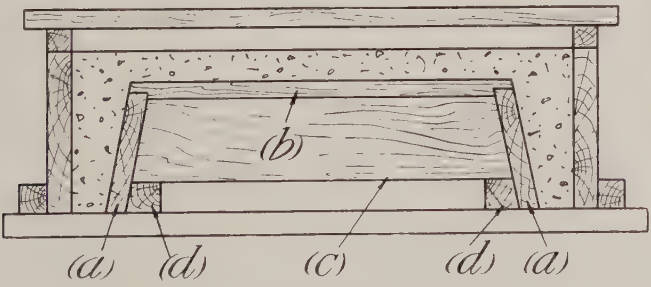


Fig. 604.

by wood clamps (*d*) nailed or screwed from the underside. These top boards are attached to the mould-sides (*a, a*) and held at right angles thereto by the brackets (*f, f*), and if necessary supported at the centre by posts (*e*). To strip this mould, remove the distance-piece and turn the mould completely over. Then take away the base, followed by the sides and the clamps holding the bevelled centre board in position. The board (*c*) is then taken out, followed by the sides (*a*), which together with the top boards (*b*) and the brackets (*f*) are made up as one piece. When the centre board (*c*) has been removed it will be found a simple matter to ease these pieces inwards and upwards, and get them out without damaging the concrete.

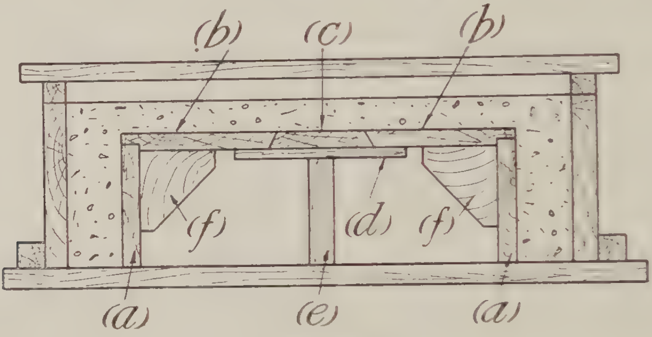


Fig. 605.

The concrete is placed in layers, and well tamped, between the outer mould and the core until the top is reached, and then spread over the core and screeded level to form the bottom of the trough.

Plaster Moulds

Moulds for ornamental stones are frequently made of plaster of Paris, which is often cheaper than wood. Except on the score of cheapness, or because it is easier for the mould to be made, there is no reason why plaster should be used in preference to wood, but when a model with a great deal of detail, or a shape that would be costly to make in wood but cheap to form in plaster with the use of a template, is to be made plaster will naturally be used for making the mould. In either case the practice of plaster modelling is followed; either piece moulds or waste moulds may be used. In the case of piece moulds, a model is first made in clay, plaster, or other material and surrounded with plaster about an inch thick in sections of a size that can be easily handled.

Before building up the plaster mould, the whole of the model should be shellaced and oiled to prevent the plaster adhering to it. Often the shape of the model will determine the size of the pieces, as it must be possible to withdraw each piece separately. The number and size of the pieces will vary with each model to be copied. A typical plaster piece mould is shown in *Fig.* 606 in which an idea is given of the method of dividing the mould so that each piece can be removed from the model without damage. It will be noted that where an undercut occurs on the model a separate piece is used.

As it is completed, the edges of each piece of the mould must be trimmed level and oiled to prevent the following sections adhering to the one already in place; sometimes greased paper is used for this purpose. If desirable on account of the size or shape of the mould, joggle joints should be formed in the sections so that they will hold in place when reassembled.

When the whole of the model has been covered with sections of the plaster piece mould, the latter is varnished and oiled on the outside and jacketed; that is, covered with an outer shell of plaster, as shown in section in *Fig.* 606. This outer jacket is used as a container to hold the piece-mould when it is used for casting the stone, and must also be in sections so that it can be stripped; it is usually sufficient to divide it in halves vertically.

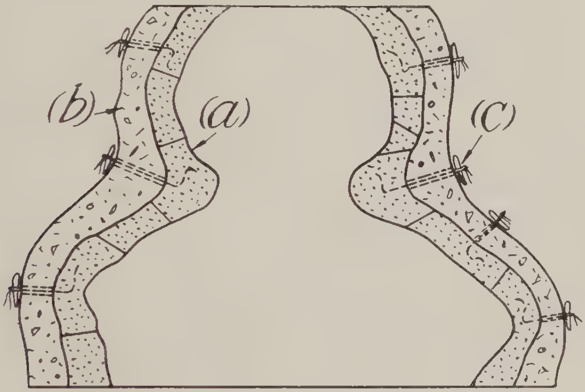


Fig. 606.

When the plaster has hardened, the outer jacket is removed, followed by the sections of the piece mould. If a clay model has been used, any adhering clay must be scraped from the plaster, and the pieces again oiled before re-assembly in the jacket. In a mould of a shape such as that shown in *Fig.* 606, after the pieces have been assembled in each half of the jacket the mould is placed in a vertical position and tied together with cord or wire. It might here be noted that when the shape of the mould is such that any section of the piece mould would, unless supported, fall when the mould is erected, these sections are fastened to the jacket. The usual method is to cast the end of a piece of string into the section when it is

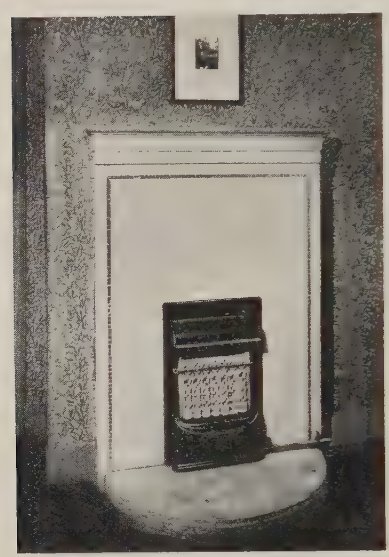
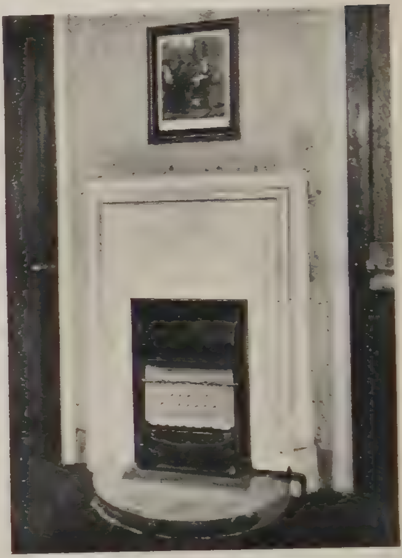


Fig. 607.



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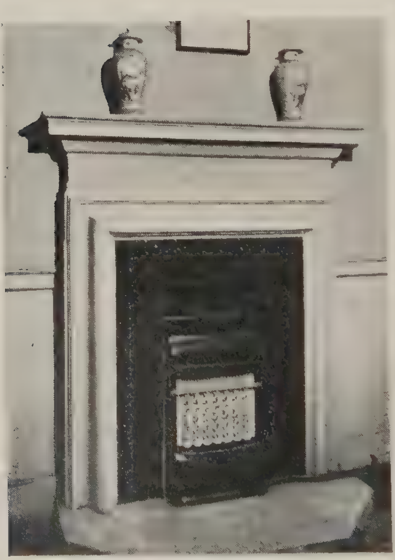

Fig. 609.

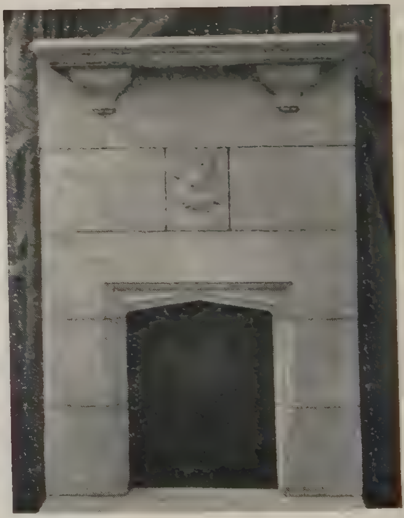

Fig. 610.

Cast Stone Fireplaces.

made so that the other end may be passed through a hole in the jacket and secured ; this is explained in *Fig.* 606, where this method of fastening is demonstrated.

When the mould is completely re-assembled and securely fastened,

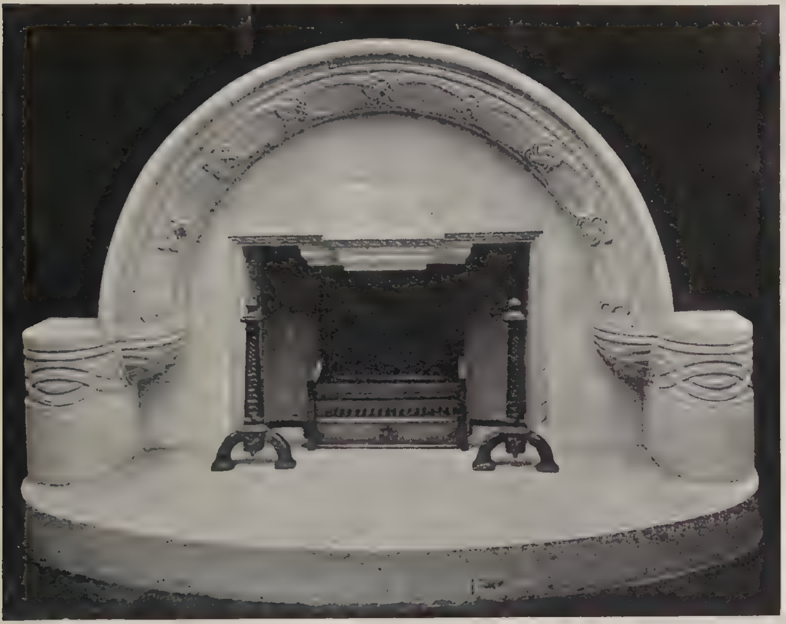

Fig. 611.—Cast Stone Fireplace.

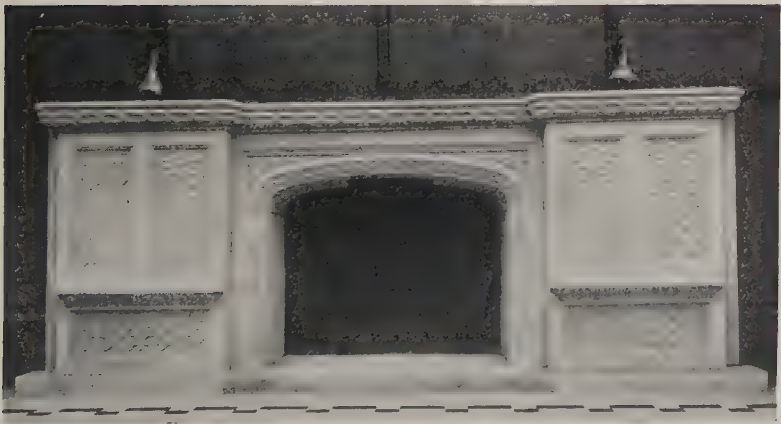

Fig. 612.—Cast Stone Fireplace.

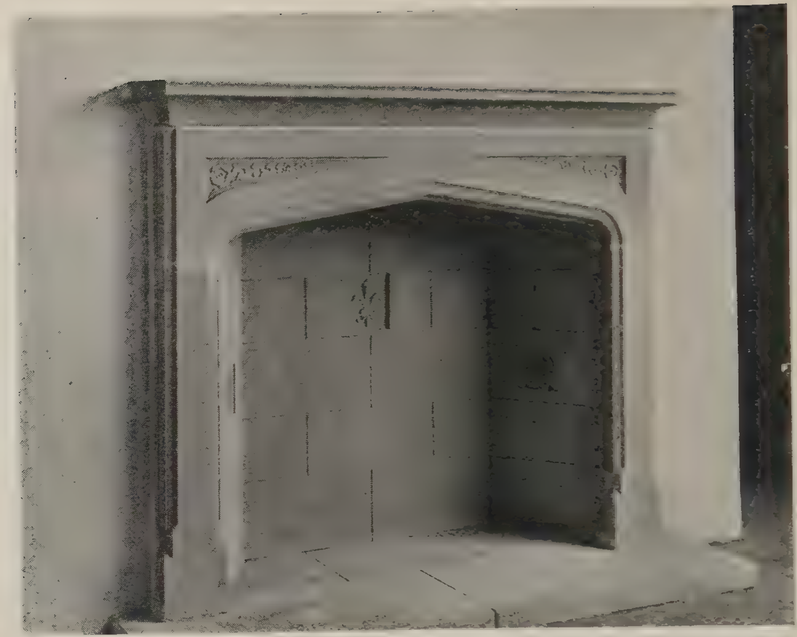

Fig. 613.—Cast Stone Fireplace.

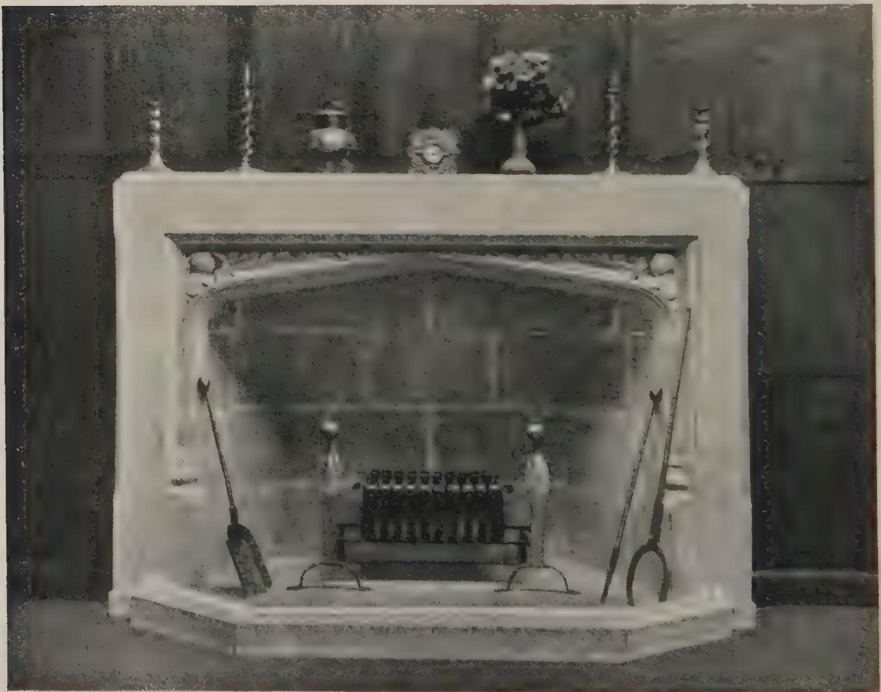

Fig. 614.—Cast Stone Fireplace.

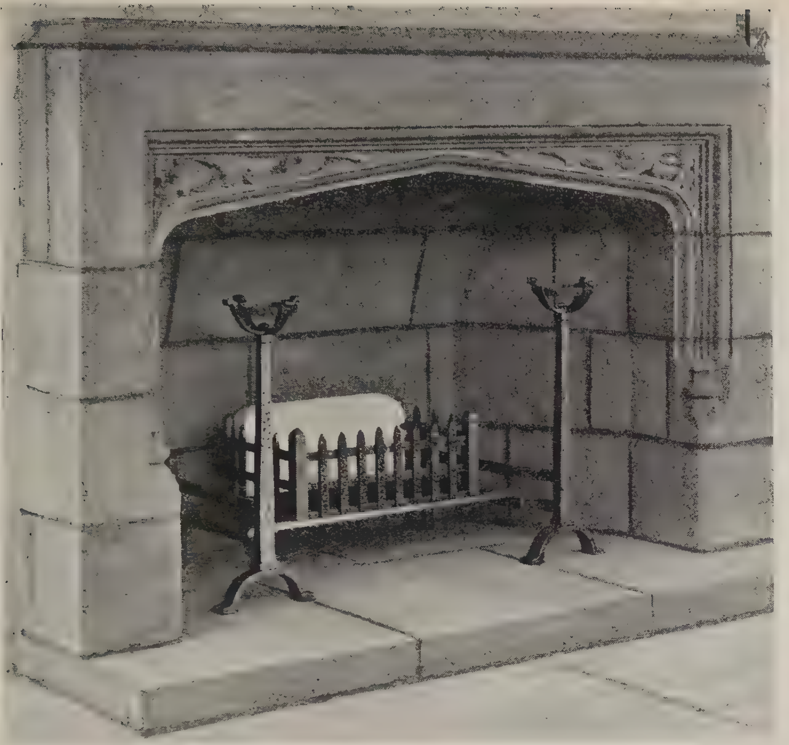

Fig. 615.

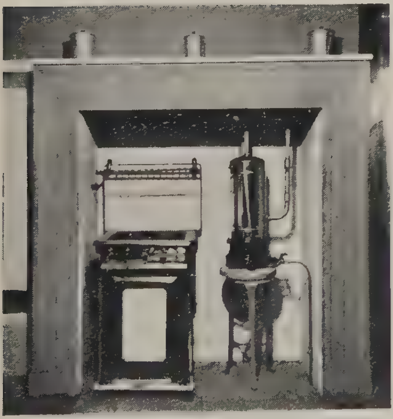

Fig. 616.

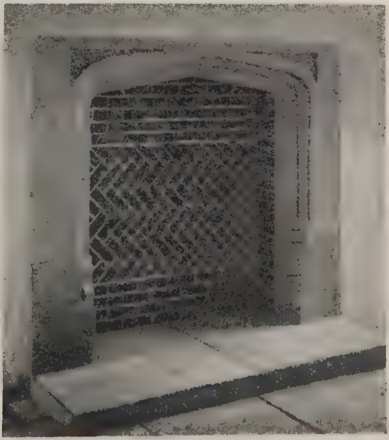

Fig. 617.

Cast Stone Fireplaces.

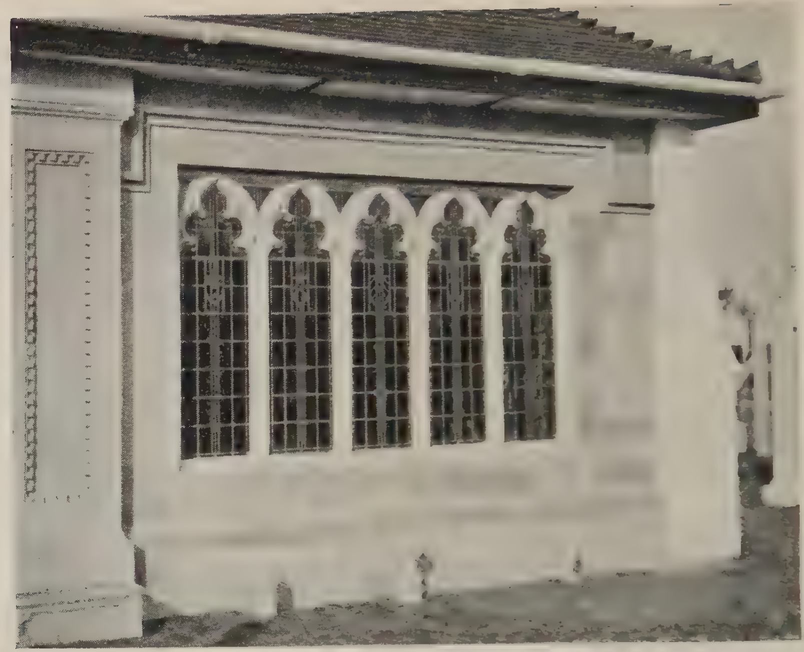

Fig. 618.—Cast Stone Window.

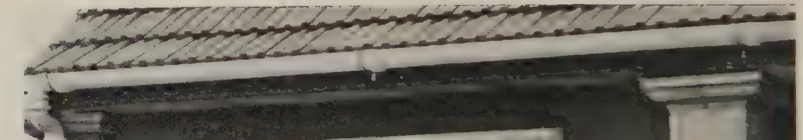

Fig. 619.—Cast Stone Window.

concrete is placed in from the top. Owing to the danger of damaging the mould by heavy ramming, a fairly wet concrete is used. This should be placed in layers of two or three inches at a time, and each layer thoroughly stirred, and pressed down as firmly as possible without injuring the mould, in order to force it into the detail of the mould and also to allow any entrapped air to escape. Owing to the excess water used it will often be found that a few hours after casting the concrete has sunk below the top of the mould, in which case more is added to fill. This additional material should be added while that already poured is still green in order to obtain a good bond.

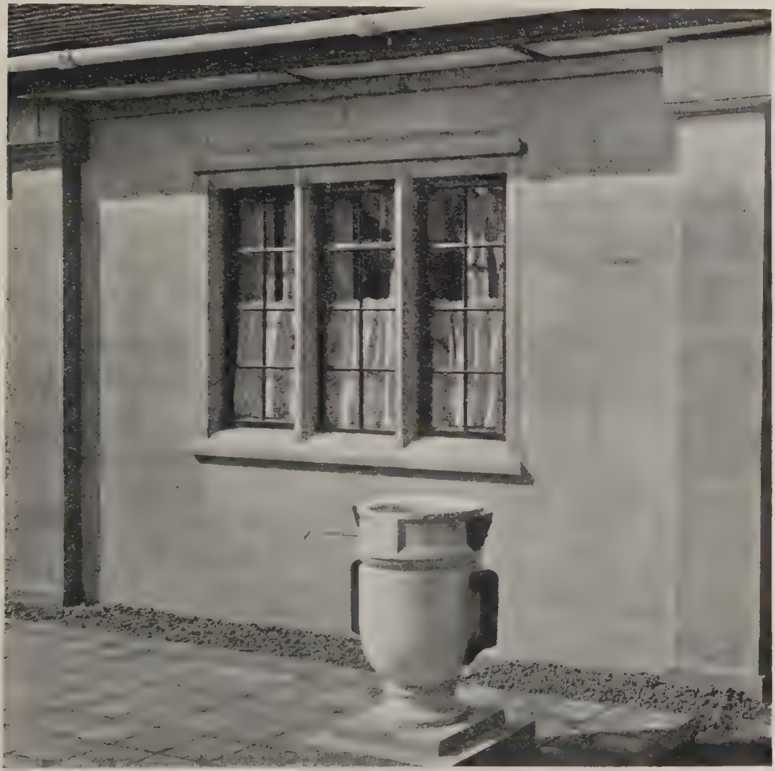

Fig. 620.—Cast Stone Window, Wall, and Vase.

Plaster Waste Moulds.—If a plaster mould is to be used once only it is often simpler to use a " waste " mould, that is, a mould which may be broken away from the stone after the latter is hard. In this type of

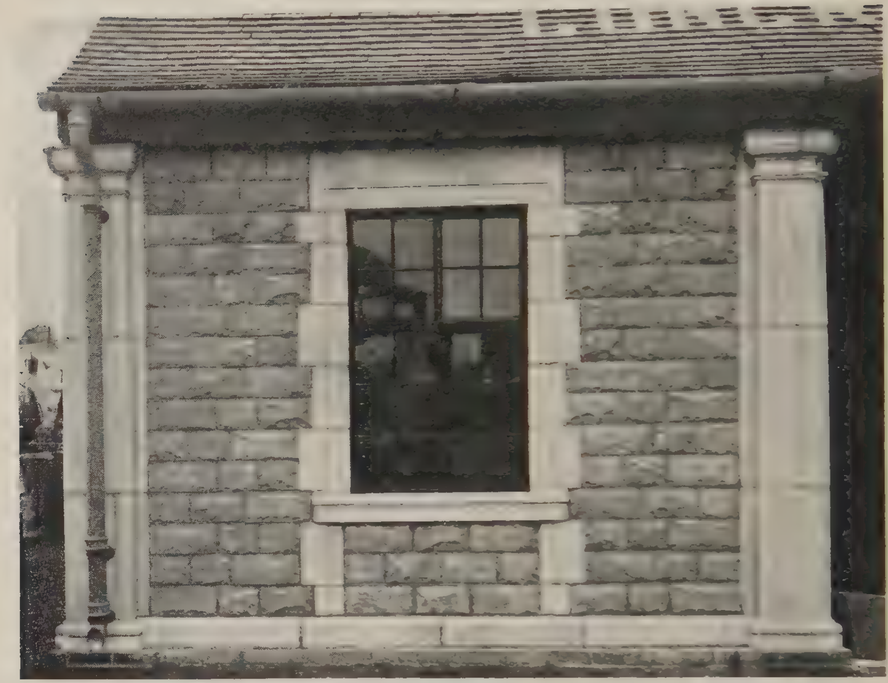

Fig. 621.—Cast Stone Wall and Window.

mould there is no need to make separate pieces to allow for easy withdrawal, and the work is thus cheapened and simplified.

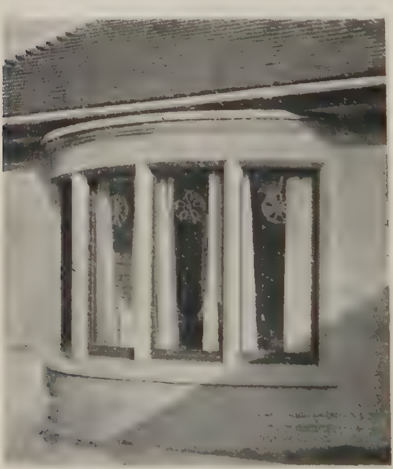

Fig. 622.—Cast Stone Bay Window.

Running Moulds. — Templates are frequently used in the manufacture of plaster moulds, again following the practice of the plaster modeller. An example is shown in *Fig.* 624, and this is sufficient to demonstrate the principle. The stone to be made is a coping for a balustrade, shown in section to the right of the sketch of the mould, also shown in section. As will be seen, the stone is made face down. In the sketch (*a*) is a boxing of the same width as the stone and of a depth a few inches deeper to allow for the plaster (*b*). The plaster is placed in the bottom of the box and run with

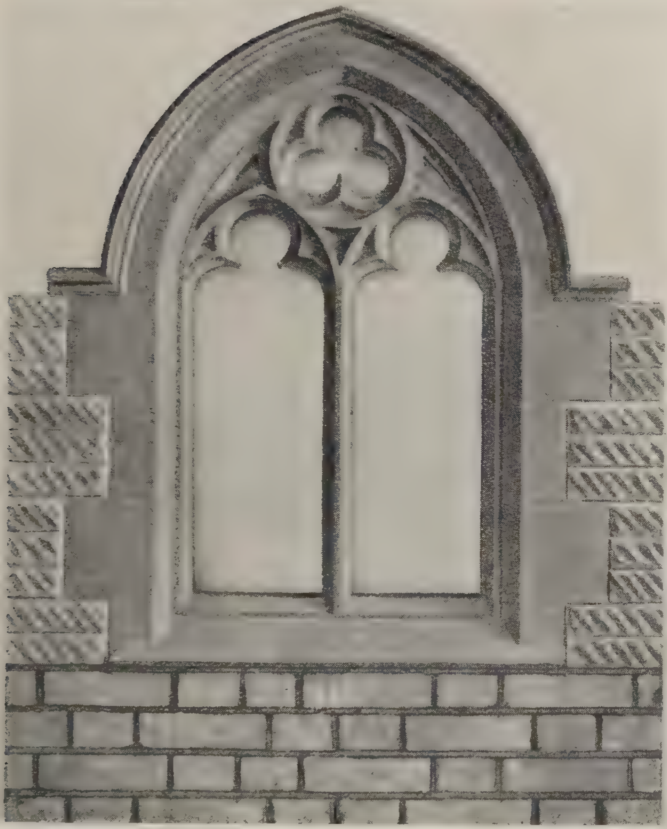

Fig. 623.—Cast Stone Window.

the template (*c*) to the contour of the top of the stone. When the plaster is hard it is shellaced and oiled and concrete filled to the level of the top of the box in the usual way.

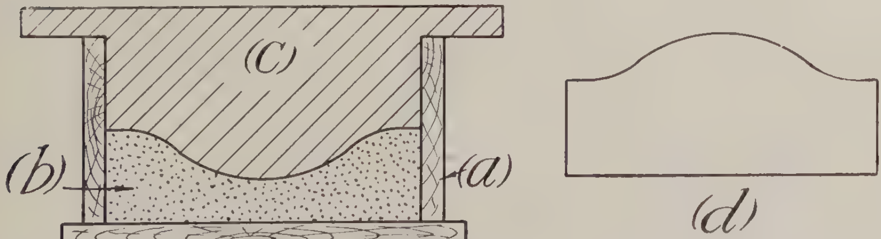

Fig. 624.

Sand Moulds. Sand moulding of concrete is an innovation of comparatively recent date in this country, and although it is not claimed to be much cheaper than other methods it has certain advantages, the chief of which is that it permits the use of very wet mixes without serious loss of strength ; this is due to the fact that the sand used for the mould absorbs the excess water from the concrete.

Whereas in all types of rigid and semi-rigid moulds several stones can be made in one mould, in sand moulding a separate mould has to be made for each article. As, however, the mould material is sand, this is not such a serious item as it might appear at first sight. Often, indeed, it may take no longer to make a sand mould than to assemble a rigid mould ; the labour of stripping is simplified because it is only necessary to knock the sand away from the stone ; the cost of materials is reduced because the same sand can be re-used while the wood or plaster used for a rigid mould is often of no further use and its cost a direct charge on one stone.

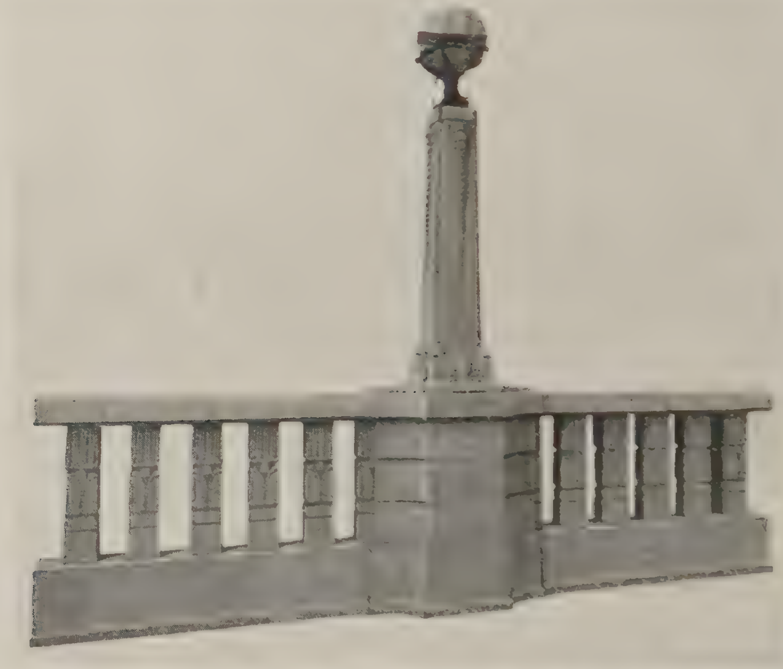

Fig. 625.—Cast Stone Bridge Balustrade and Lamp Standard.

The principle of moulding concrete in sand is practically the same as iron moulding. A model is first made of the stone to be reproduced, and this can be in wood, plaster, or other material sufficiently strong to allow

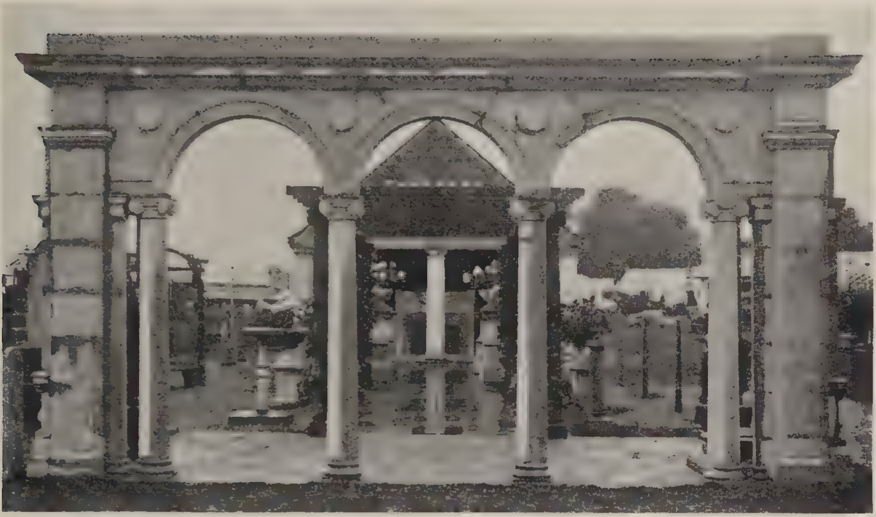

Fig. 626.—Cast Stone Screen.

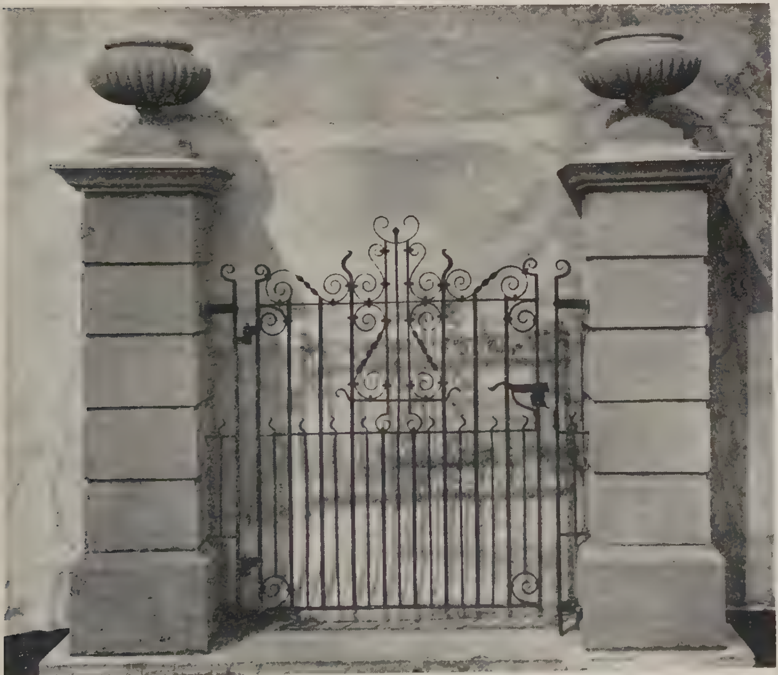

Fig. 627.—Cast Stone Gate Pillars.

of damp moulding sand being rammed hard against it. The mould may be made either direct on a floor or framed with a boxing; the method will generally depend on the shape and size of the stone to be made. *Fig.* 628 shows diagrammatically the principle, in its simplest form, of a sand mould made direct on a floor. It is simply a space left within a heap of sand. To make such a mould (see *Fig.* 628), prepare a wood model (*a*), place it on a layer of well-rammed sand, heap sand against the four sides and ram it against the model. In a framed model of this type it is desirable to form one or two stays as at (*b*), so that when the sand has been rammed they may be used to withdraw the model, leaving a mould as on the right of the diagram.

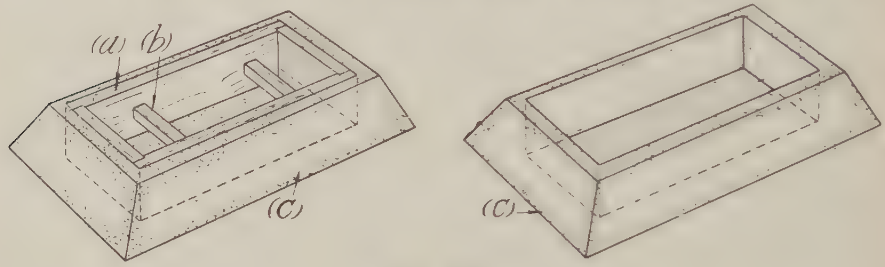

Fig. 628.

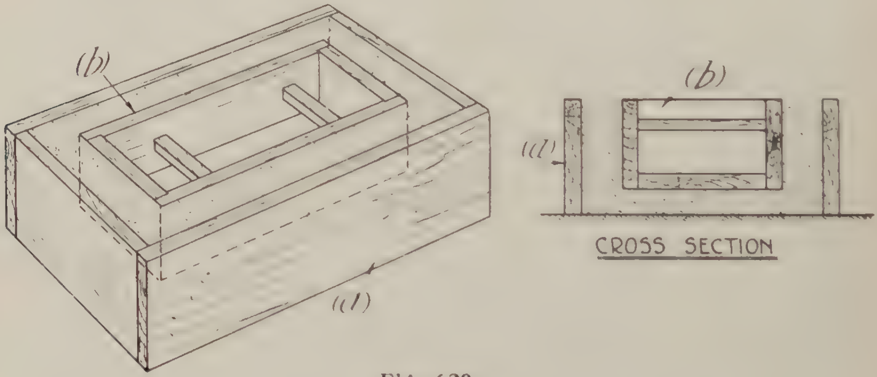

Fig. 629.

If an outer frame is used, the mould is formed as in *Fig.* 629, showing such a mould in perspective and section. The outer frame is shown at (*a*), and this should be at least 6 in. larger than the model in all three dimensions. A layer of 6 in. of sand is placed in the bottom of the frame and well rammed, and on this the model (*b*) is placed. Sand is then thoroughly rammed between the model and the outer boxing so that when the model is withdrawn its shape is left in the sand.

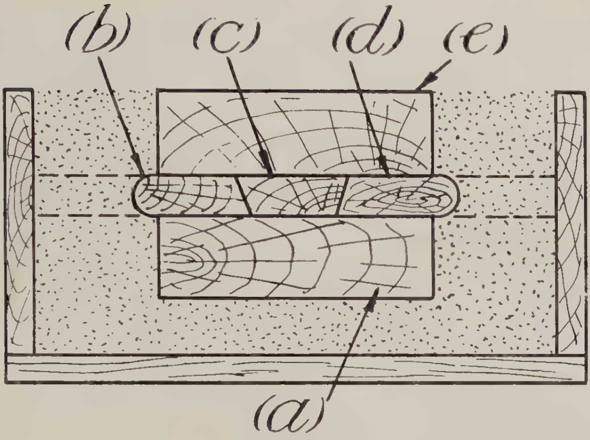

Fig. 630.

Whether the stone be moulded face up, face down, or side face, depends upon its shape, wherever possible forming a flat surface of the stone at the top of the mould so that it can be screeded level. If the stone is undercut or has projections on its face or sides the model will have to be made in more than one piece in order that it will be possible to withdraw it. This is shown in principle in *Fig.* 630, a section through a mould and model for a stone with a rib on each side. The model is shown in five pieces.

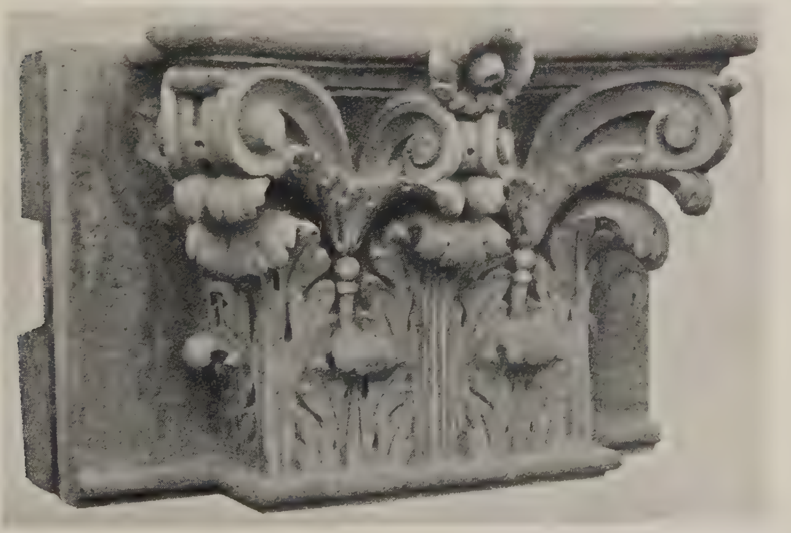

Fig. 631.—Decorative Cast Stone.

Part (*a*) is placed first on a sand bed and sand compacted around it to the level of the lower dotted line; next parts (*b*) and (*c*) and (*d*) are placed in position and sand compacted to the level of the upper dotted line; finally part (*e*) is placed and sand rammed to the top of the mould. To remove the model part (*e*) is first lifted out, followed by the wedge-shaped piece (*c*). The removal of (*c*) allows part (*b*) to be eased towards the centre of the mould, and lifted out without disturbing the sand, and (*d*) is taken out in the same way, leaving the bottom piece (*a*) to be lifted last. In a volume such as this it is only possible to give general principles, and the examples illustrated demonstrate the method sufficiently well for a sand mould for any shape of stone to be devised.

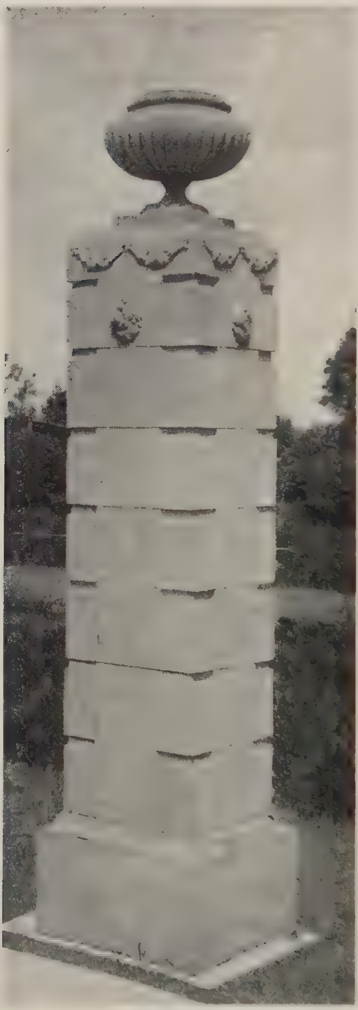

Fig. 632.—Concrete Column or Gate Pier.

When making sand moulds it, of course, often happens that the surface of the sand is damaged when the model is removed; when this happens the mould is made good with a trowel, float, or other suitable tool. It will be realised that the concrete must be placed very gently in a sand mould to avoid breaking it down.

Stones made in sand moulds may be finished in the same way as stones made in other types of moulds, although customers often prefer sand-moulded stones just as they leave the moulds owing to the special surface imparted to them by the method of moulding.

Concrete Moulds.—The use of concrete for moulds follows plaster mould practice, the only difference being that the moulds take longer to make owing to the longer time concrete requires to harden. The concrete mould has, of course, a much longer life than the plaster mould; it is, in fact, indestructible, and may be kept out of doors without fear of deterioration. Also, a concrete mould will not twist or get out of shape as a wood mould is likely to do when in use. Concrete moulds are not to be recommended for the manufacture of one or two castings, but for the production of a large number of stones of the same shape they have many advantages. Owing to their weight they are not suitable for very large castings. A drawback is that concrete moulds cannot be easily altered, as can wood moulds, to suit a different shape stone.

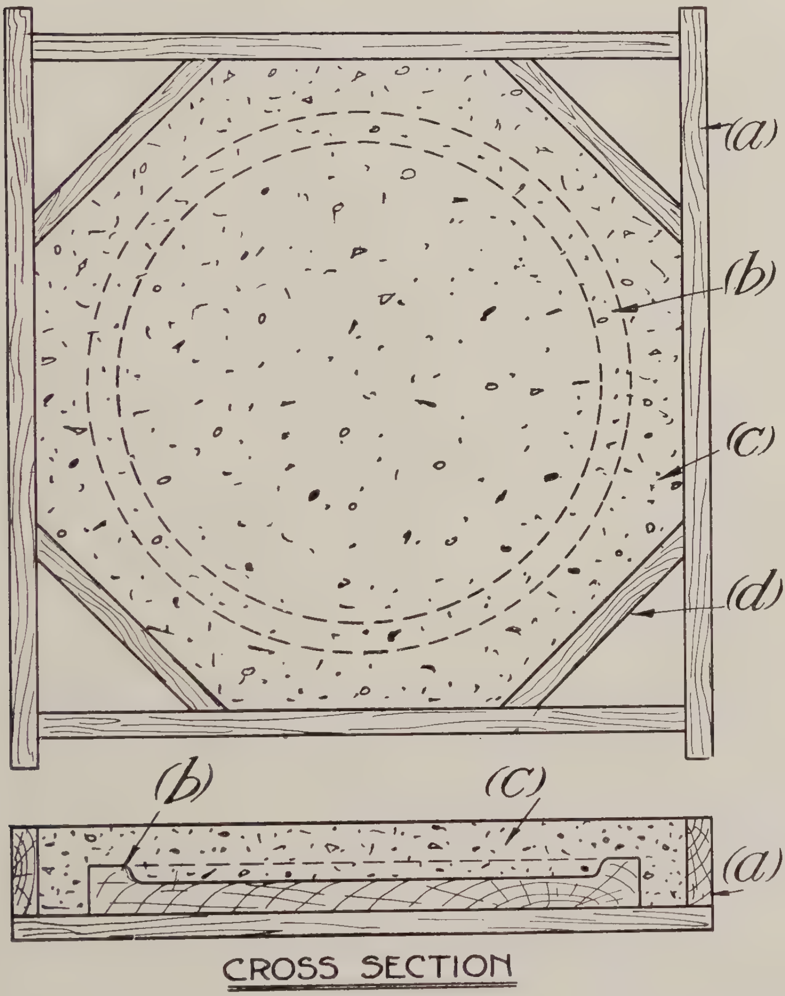

Fig. 633.

Concrete moulds are made from models of the stone to be made, and due to the comparatively slow-setting properties of cement compared with plaster it is necessary to form a boxing around the model when the concrete is poured. As a smooth face is necessary, only fine sand should be used as aggregate, while the addition of hydrated lime will make a "fat" mix which is easily worked. A mix of 1 part Portland cement to 2½ parts fine sand with the addition of 15 per cent. of "Hydralime" per weight of cement is a suitable concrete for mould making.

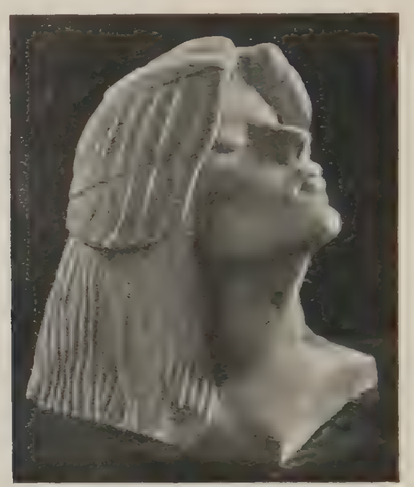

Fig. 634.—Sculptured Head in Concrete.

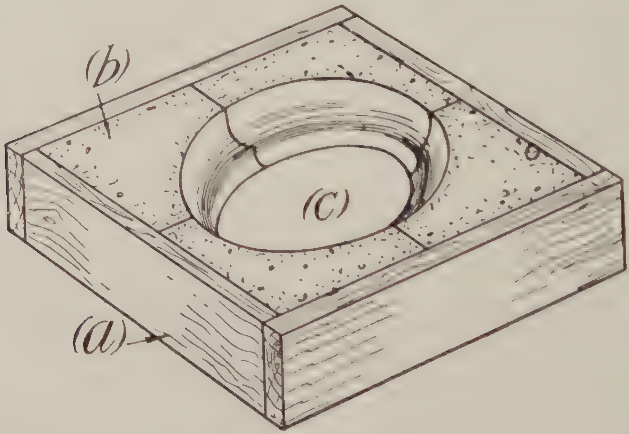

Fig. 635.

The method of making concrete moulds is shown in *Fig.* 633, a plan and section of a mould for making a circular plaque with a raised edge.

The outer frame (*a*) is larger than the overall size of the model by the desired thickness of the mould ; the corners are blocked off by the strips (*d*) in order to lighten the mould and avoid waste of material. The model (*b*) is placed in the bottom of the box and concrete (*c*) filled around the sides and screeded level with the top of the box. If necessary a mesh reinforcement should be embedded in the mould to strengthen it. To release this mould, all that is necessary is to turn it upside down, lift out the model, and remove the boxing. Before placing the concrete the model and boxing should be oiled, and the mould should also be oiled each time before use.

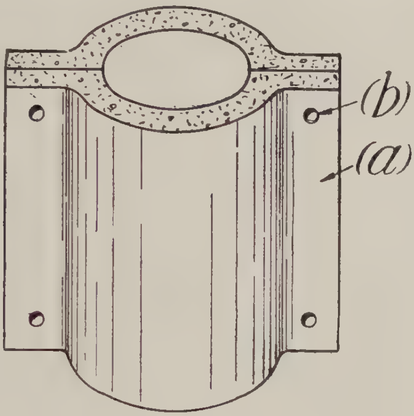

Fig. 636.

Concrete moulds are more difficult than wood to assemble if made in several parts, so that it is desirable to keep the parts as few as possible. A plaque, or bird-bath mould, such as is shown in *Fig.* 633, is an ideal shape to make in a concrete mould. When it is necessary to make a concrete mould in more than one part, the parts may either be assembled in a box (as in *Fig.* 635) or fixed together. A simple method is to cast lugs on the different parts so that they can be bolted together, as shown in *Fig.* 636.

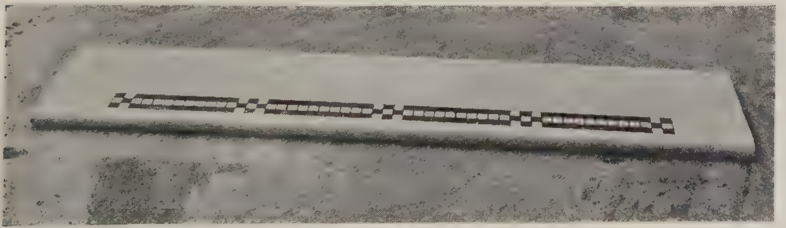

Fig. 637.—Cast Stone Stair Tread.

These lugs (*a*) are formed when the mould is made with holes to take the bolts and wing-nuts (*b*).

Gelatine Moulds.—For stones with a great deal of undercutting, and which would be difficult to mould in plaster, gelatine moulds may be used. The method is shown in diagrammatic form in *Fig.* 640, which for the sake of easy explanation does not show detail on the model. The model (*a*) is covered with a layer of clay (*b*), which in turn is covered with a plaster

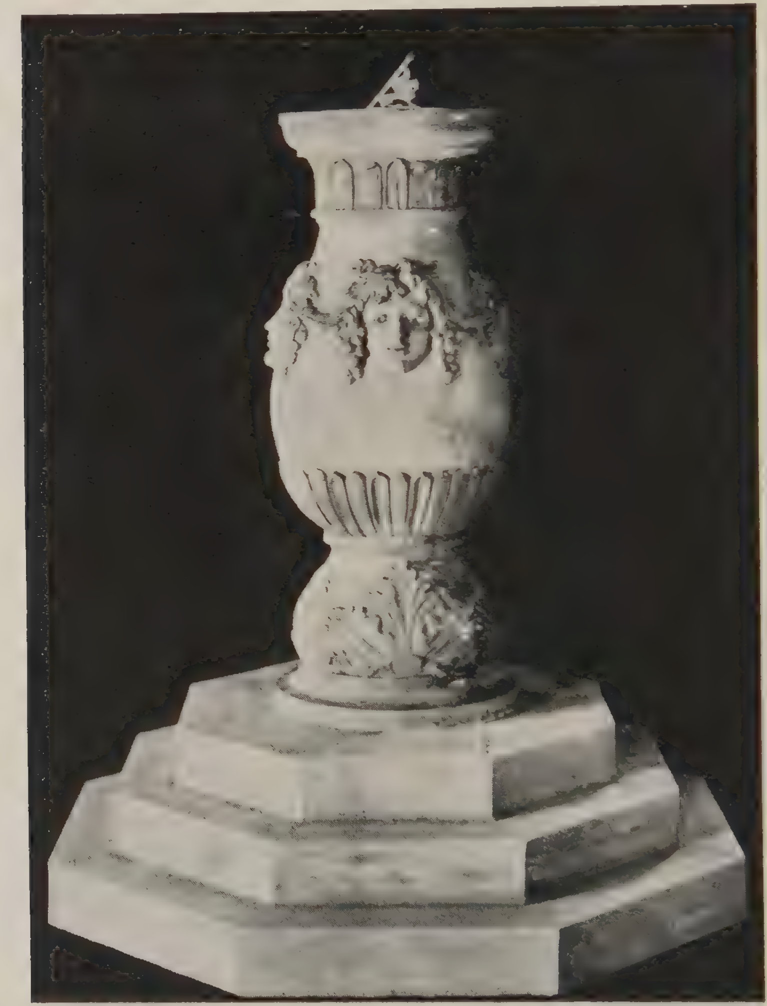

Fig. 638.—Cast Stone Vase.

jacket (*c*) made in sections so that it will draw. When the plaster is hard the jacket (*c*) is removed and the clay scraped from both the model and the jacket. The model and jacket are then re-assembled, so that the space originally occupied by clay is available for pouring hot gelatine. Finally, when the gelatine has hardened, the jacket is removed, the gelatine cut in removable sections and removed from the model, and the model placed at one side. The mould is formed by placing the gelatine sections in position within the plaster jacket, so that concrete can be poured from the top.

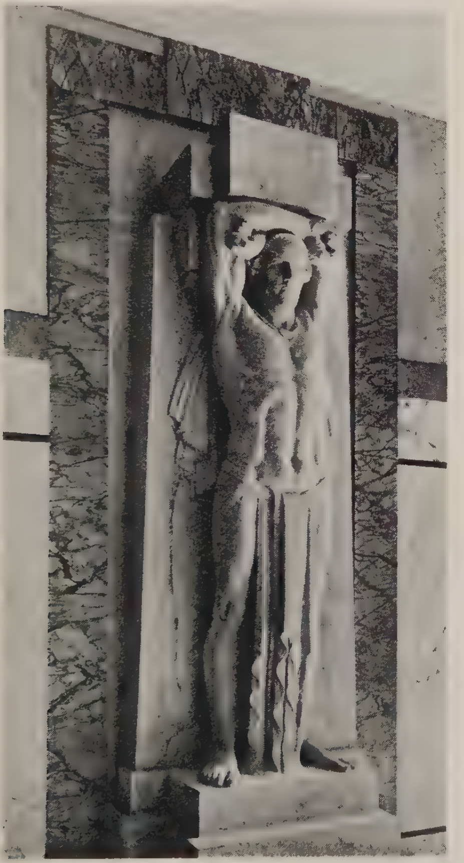

Fig. 639.—Carved Concrete Figure at Portland House.

In gelatine moulds only wet concrete may be used, as ramming a drier concrete would damage the mould. The concrete must, however, be thoroughly stirred with a rod as it is placed in the mould. Before use the

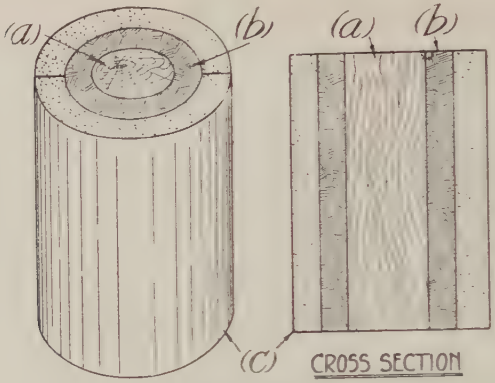
(a)
(b)
(a)
(b)
(C)
CROSS SECTION

Fig. 640.

gelatine must be shellaced to prevent damage by the wet concrete, and oiled each time it is used.

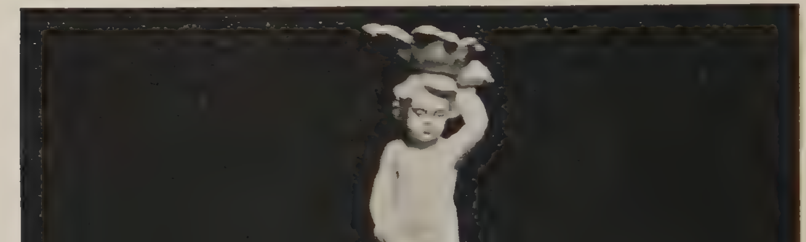

Fig. 641.—Concrete Garden Ornaments.

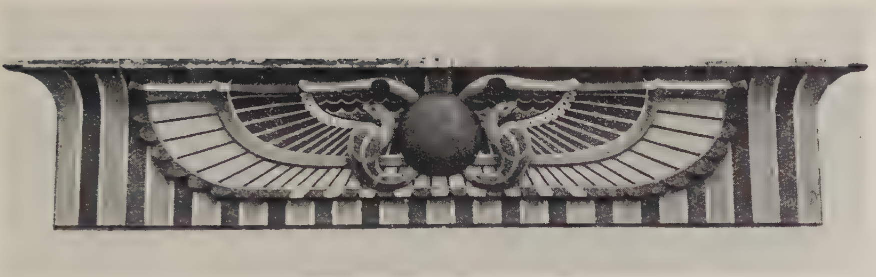

Fig. 642.—Coloured Concrete Decoration on London Factory.

With the aid of the foregoing notes and the accompanying diagrams a little ingenuity should enable an intelligent worker to make a mould for any shape of cast stone.

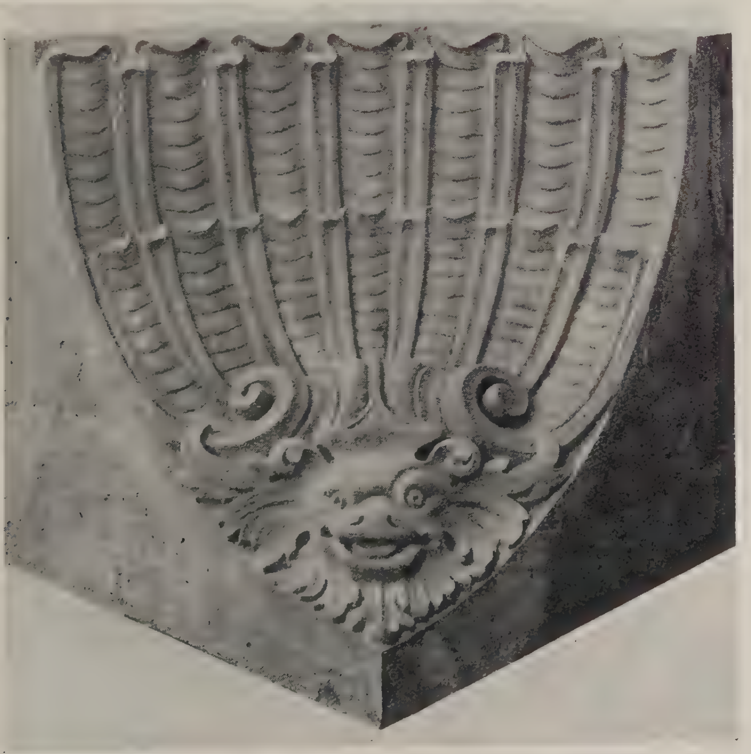

Fig. 643.—Cast Stone Architectural Detail.

PART VIII

CONCRETE PRODUCTS

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CONCRETE PRODUCTS

THE quality of concrete used for concrete products depends upon the use for which they are required. For the ordinary run of blocks and slabs for the walls of houses, etc., a 1 : 2 : 4 mix with good Portland cement and clean graded ballast aggregate is suitable. If a high degree of water-tightness is required, such as in blocks for lining reservoirs, sea-walls, etc., a richer mix, say, 1 : 1½ : 3 is to be preferred. Articles subject to abrasion, such as paving flags, should be made with granite aggregate and with a fairly rich mix, say, a 1 : 3 mix of cement and graded crushed granite. If a special face mixture is required, this is placed in the mould separately as described for cast stone. For small articles, especially ornamental pieces, the coarse aggregate should not be larger than sand size and the mix should not be leaner than 1 : 3. The size of the aggregate for larger products up to the size of, say, 18 in. by 9 in. by 4½ in. building blocks should as a rule not exceed ½ in. For larger blocks an aggregate graded from 1 in. down, or even larger, may be used.

Machine Production

Blocks and Slabs.—Successfully to compete with other cheap building materials, concrete products such as blocks, bricks, flags, roofing and floor tiles, pipes, etc., must be made by mass production methods, and for this purpose special machines are available. In most of these machines the essential features are quick assembly and opening of the mould and the removal of the product on the pallet on which it has been made. A semi-dry concrete is generally used, which, in conjunction with the tamping or pressure applied by the machine, results in a product so compact that it will stand up if the sides of the mould are taken away immediately the concrete has been tamped or pressed.

It is not the intention here to give detailed descriptions of machines, moulds, and processes used in the manufacture of every type of concrete product. For many products wood or other types of moulds are made by the products manufacturer on the principles already described, and after a study of the foregoing notes it should be a simple matter to devise moulds for any shape of product.

For mass production of many units of the same size and shape, machines are available and some of these are illustrated in *Figs.* 644 to 660. In all

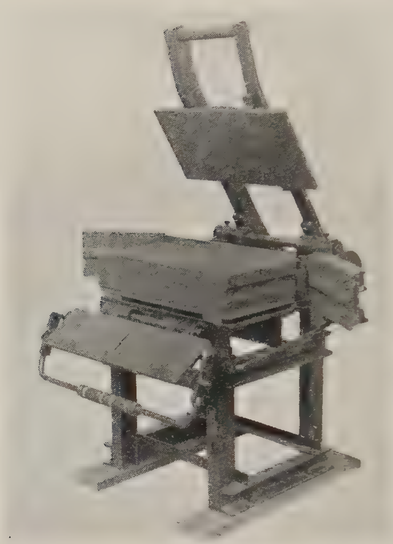

Fig. 644.

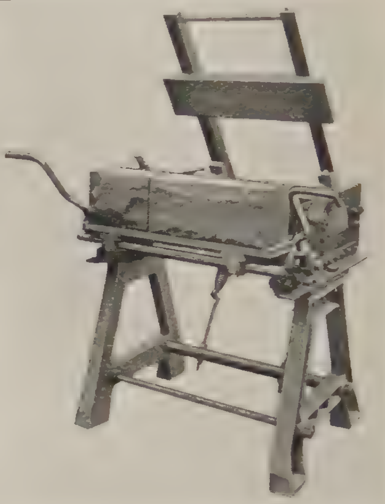

Fig. 645.

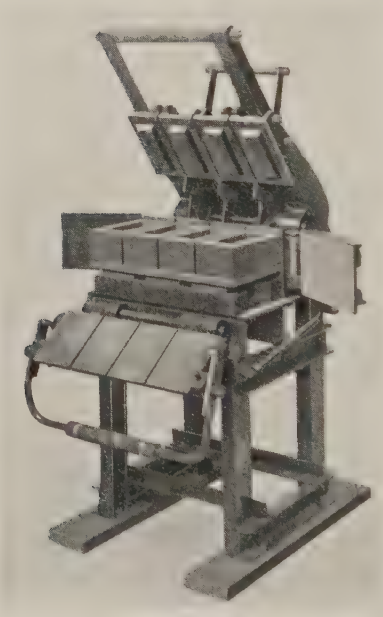

Fig. 646.

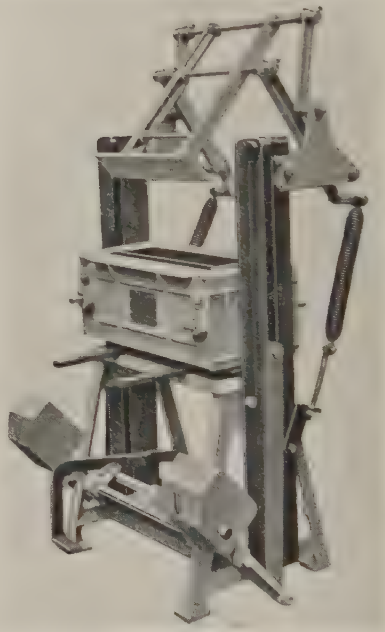

Fig. 647.

Block, Slab and Brick Machines.

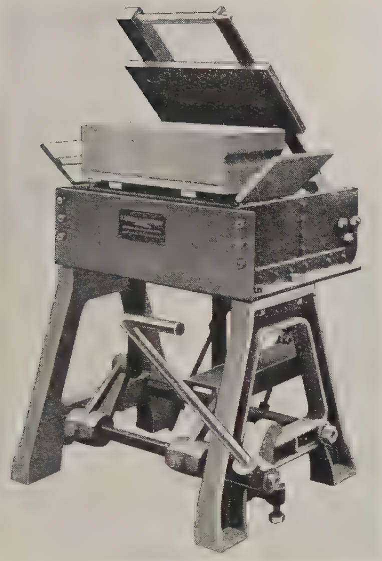

Fig. 648.

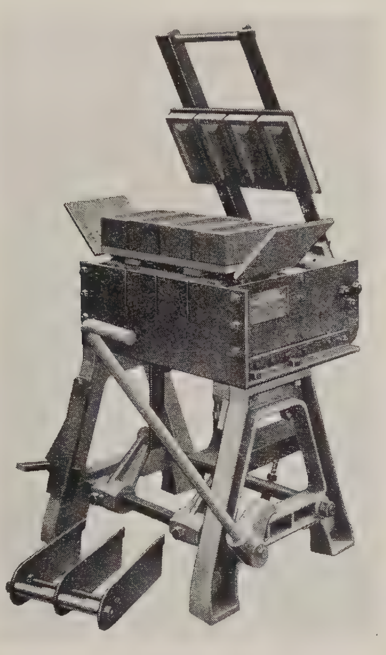

Fig. 649.

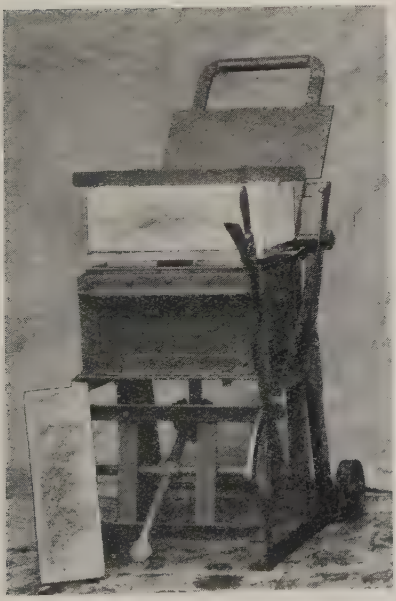

Fig. 650.

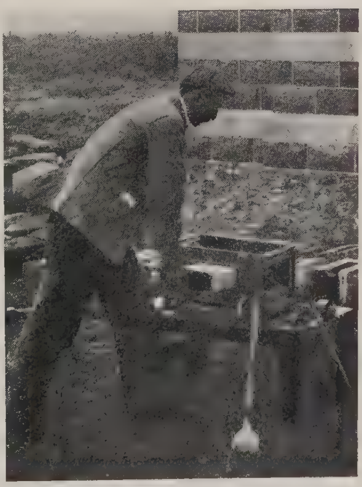

Fig. 651.

Block and Slab Machines.

cases a fresh pallet is placed in the bottom of the mould for each unit to be made. The methods of releasing the product from the mould differ. In some cases the sides of the box are hinged so that they can be dropped and the pallet containing the product lifted out (see *Figs.* 644 and 646, 647); in others by operating a hand or foot lever the pallet and product are extruded above the mould box for removal, and after the product has been taken away the release of the lever allows the mould bottom to drop ready for another pallet (see *Figs.* 648–650).

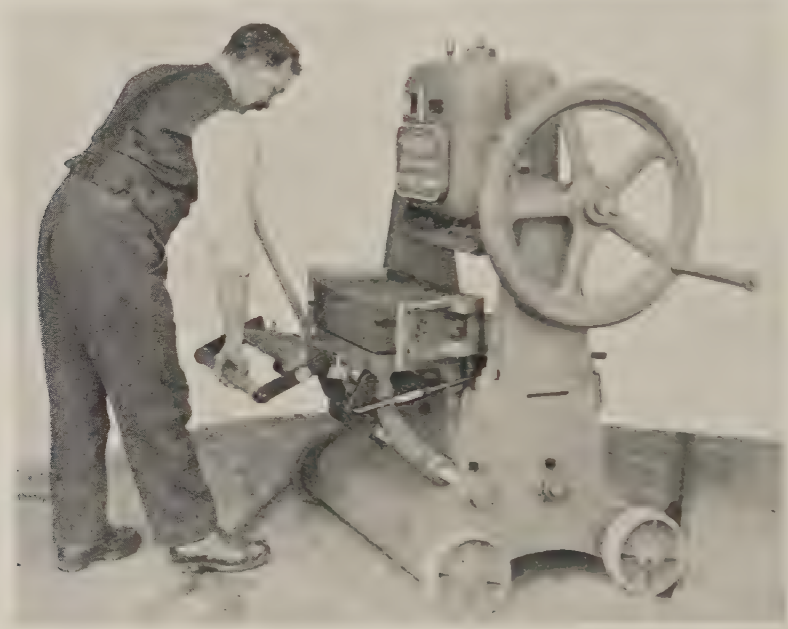

Fig. 652.

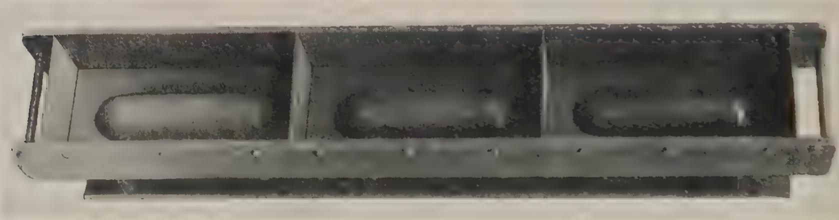

Fig. 653.—Brick Mould.

Methods of consolidating the concrete also vary with these machines. In some tamping is done by slamming down a hinged plate (see *Figs.* 644–650); in others the material is rammed into the mould by a heavy rammer (see *Fig.* 651). In other types of machines pressure is applied by turning a wheel which forces a top plate into the mould box (*Fig.* 652). Still other machines have both top and bottom pressure applied by similar means.

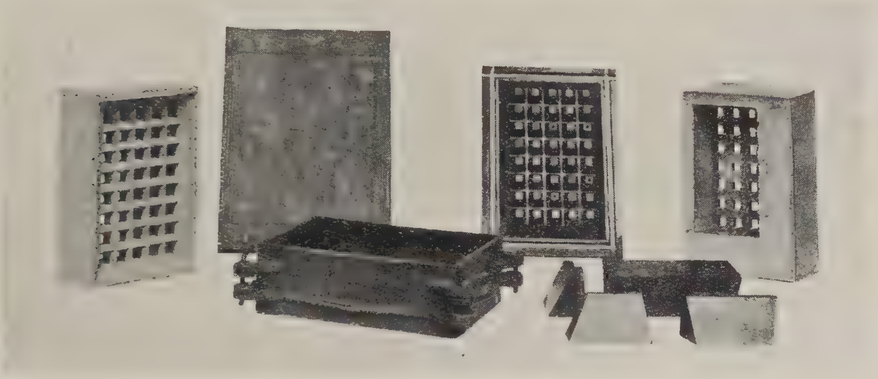

Fig. 654.—Air Brick and Mould.

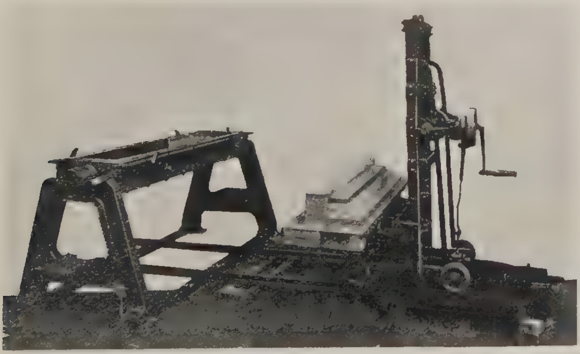

Fig. 655.

With most of the machines blocking-pieces are supplied so that smaller sizes may be produced in the same mould box. Dividers are also supplied for insertion in the mould so that several smaller articles can be made in the same mould.

A machine for the production of hollow blocks is shown in *Fig.* 651. The core seen in the photograph is pushed into the mould box and concrete tamped around it ; with the use of semi-dry concrete the core may be removed as soon as the material is tamped, and the block taken away for storing.

In most machines of this type a special face may be produced on the blocks or slabs by the use of special face plates ; in this case a metal face plate is put in the mould box in such a position that the blocks are made on their sides, so that when they are removed from the mould the face plate can be released and used again ; this, of course, would not be possible if the special face plate were at the bottom of the mould and served as a pallet (see *Fig.* 645).

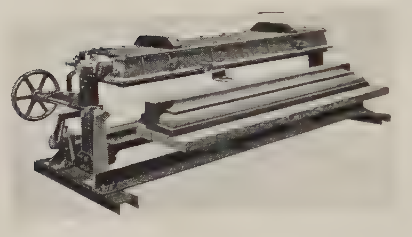

Fig. 656.

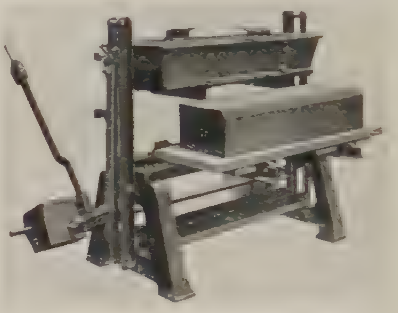

Fig. 657.

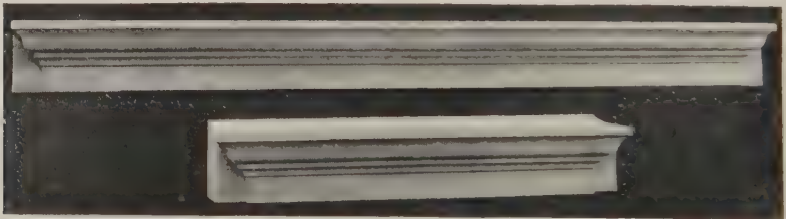

Fig. 658.—Door Lintels.

Bricks. Machines specially made for the production of concrete bricks are shown in *Figs.* 646 and 653 ; these make three or four bricks at one operation. A small hand machine for concrete bricks is shown in *Fig.* 653 ; after the mould has been filled and tamped it is turned over and the bricks extruded on to a pallet. Making three bricks at a time, this mould has considerable output.

A mould for making air bricks is shown in *Fig.* 654, consisting of an outer mould in which are fitted blocking-pieces to form the sunk face and holes.

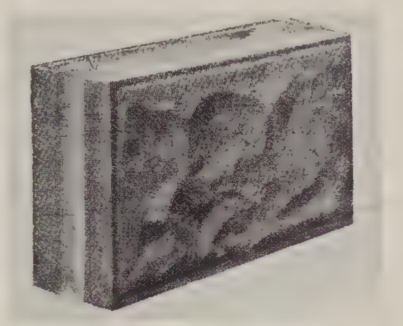

Fig. 659.—Rock-face Block.

Hydraulic machines are available for the mass production of breeze slabs by hydraulic power. These usually make four 18-in. by 9-in. by 4½-in. slabs at one operation, and produce up to 4,000 slabs a day.

For small quantities it is, of course, cheaper to make blocks and slabs in wood moulds on the principles already described, but for any considerable number the question of using a machine should be investigated.

Heads, Sills, etc.—Machines are also available for the rapid production of larger units, such as heads, sills, coping, etc. Such machines are shown in *Figs.* 655 to 657. The concrete is tamped into the mould in the usual way, the stones being

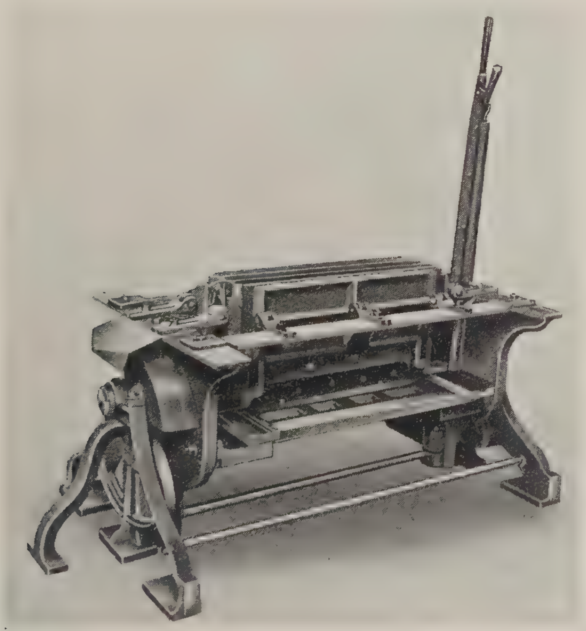

Fig. 660.—Block and Slab Machine.

made face down ; a board is then placed over the top of the mould and the whole turned over so that the stone leaves the mould and rests on the board, which serves as a pallet on which it is carried away for storage. Also supplied with this machine is a narrow-gauge track with a specially made truck with lifting platform so that heavy castings may

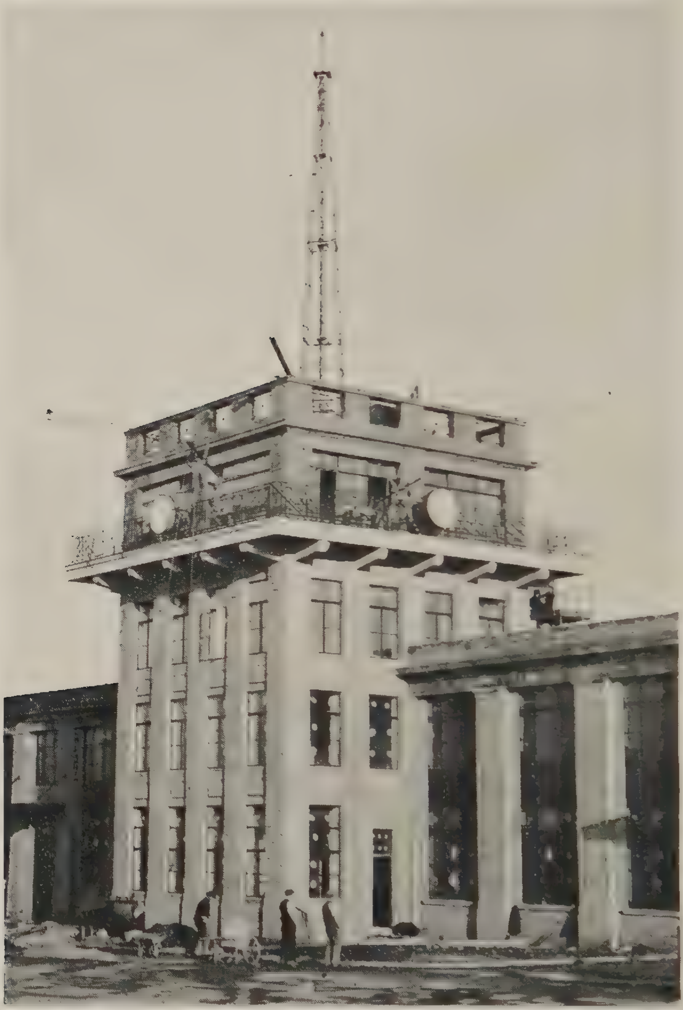

Fig. 661.—Central Tower, Croydon Air Station : Faced with Concrete Blocks.

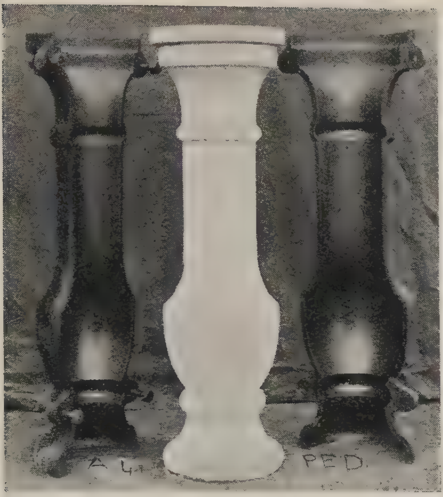

Fig. 662.—Metal Mould for Balustrade.

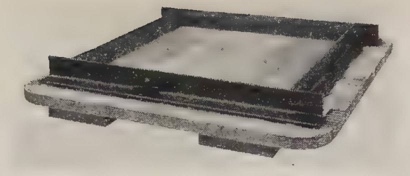

Fig. 663.—Flag Mould.

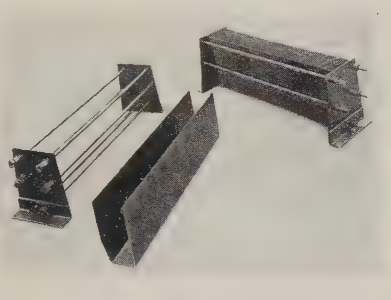

Fig. 664.—Kerb Mould.

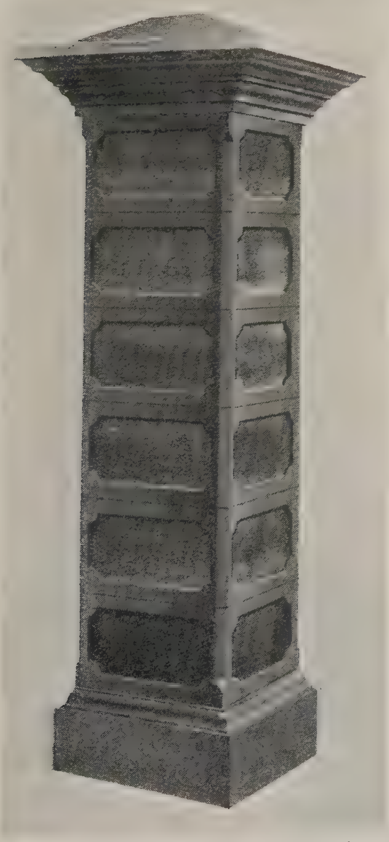

Fig. 665.—Gate Pier made in Metal Moulds.

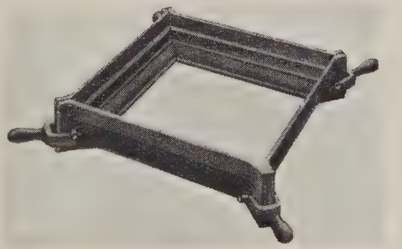

Fig. 666.—Mould for Pillar Base.

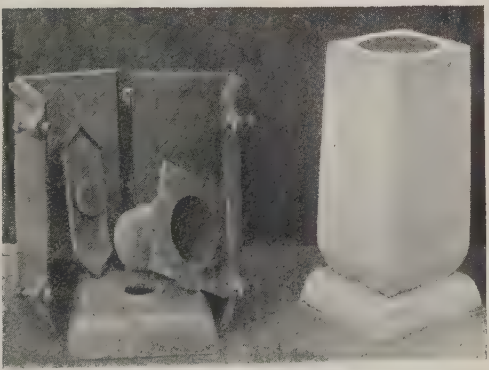

Fig. 667.—Vase Mould.

be turned from the mould direct on to the platform and taken away for storage. The same principle adapted for the production of kerb is shown in *Fig.* 657.

In other machines the products are removed from the mould by extrusion, the operation of the lever at the side of the machine raising the product on its pallet to above the level of the top of the mould box so that it can be removed for curing.

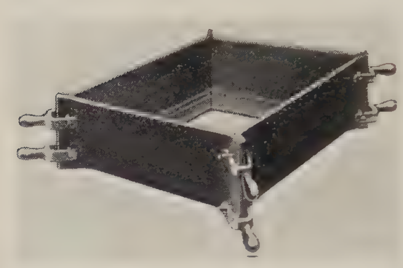

Fig. 668.—Mould for Pillar Base.

Metal Moulds.— Garden ornaments (sundials, bird baths, vases, etc.) are often made in cast-iron moulds, such as are seen in *Figs.* 662 to 669. These moulds are practically indestructible, and are simple to use. The principle, as shown in the illustrations, is to use two-piece or three-piece moulds which are fastened together by bolts and wing-nuts passing through lugs or similar devices.

Simple metal moulds are obtainable for the manufacture of paving flags, kerb, columns, balustrading, etc. The methods of using the moulds are clear from the photographs. The advantages of metal moulds for this class of work are obvious, including long life, ease of stripping and assembly, and, an important point, particularly in the case of articles such as paving flags, absence of twisting and winding. Small ornaments such as birds and animals for garden decoration are usually made in plaster or gelatine moulds.

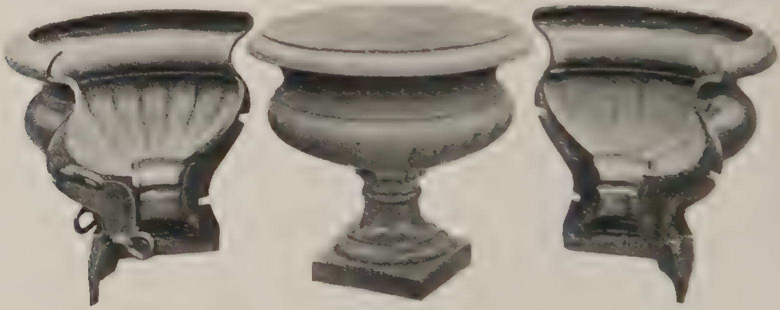

Fig. 669.—Vase Mould.

Flags.—In large paving-flag factories increasing use is being made of hydraulic presses. These machines are usually fitted with three mould-boxes on a table which rotates so that the moulds are automatically taken from the filling position to the point where pressure is applied and then to

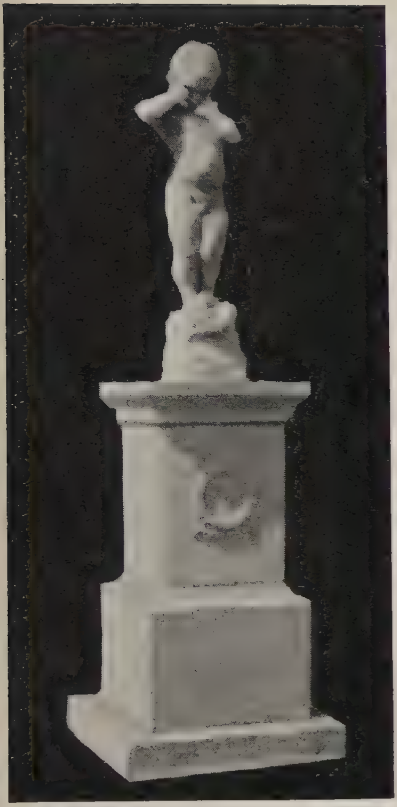

Fig. 670.—Concrete Garden Ornament.

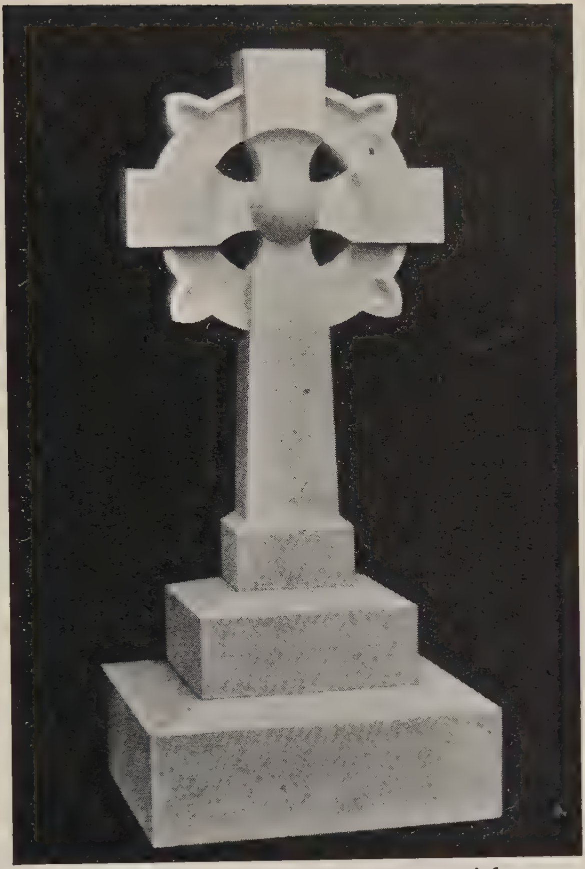

Fig. 671.—A Cast Stone Memorial.

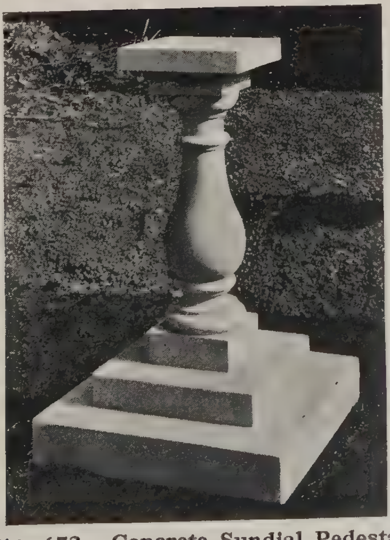

Fig. 672.—Concrete Sundial Pedestal.

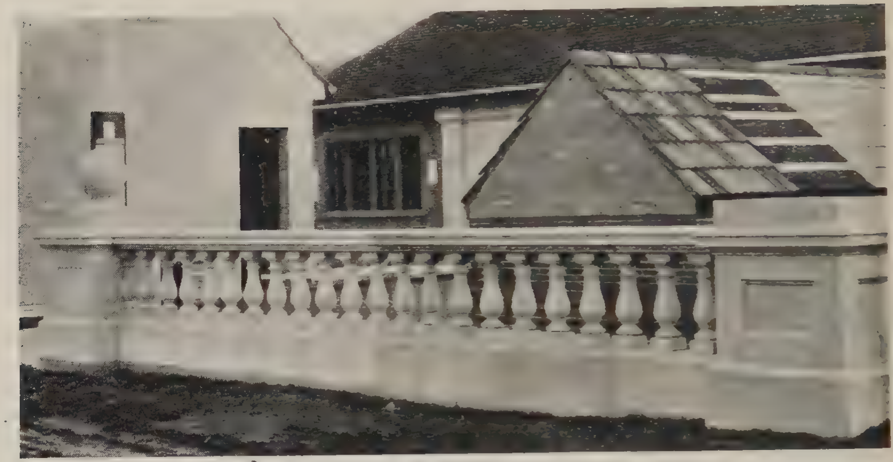

Fig. 673.—Concrete Balustrading.

the point where the flags are removed from the machine. Owing to the great output of these machines they are arranged for automatic feed from an overhead chute, and so great is the pressure that no impression can be made with the thumb after the flags leave the machine.

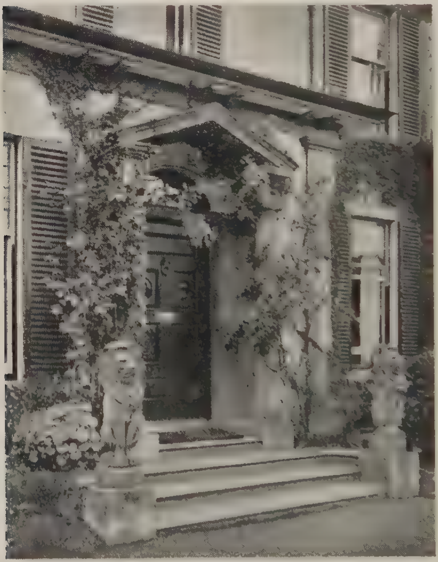

Fig. 674.—Concrete Doorway and Ornaments.

Flags may also be made in wood moulds in the form of trays, or in metal moulds such as are shown in *Fig.* 663.

Pipes.—Pipe moulds are now practically standardised of the type shown in *Fig.* 676, although some manufacturers use them in a horizontal position and vibrate them to assist the consolidation of the concrete. As will be seen, the mould consists of an outer mould and a core, both of which are designed to be easily removable. The outer mould is sometimes made in halves, the two sections being bolted together through flanges along the edges when assembled; in other types the mould has one joint which is tightened with bolts and wing-nuts in the

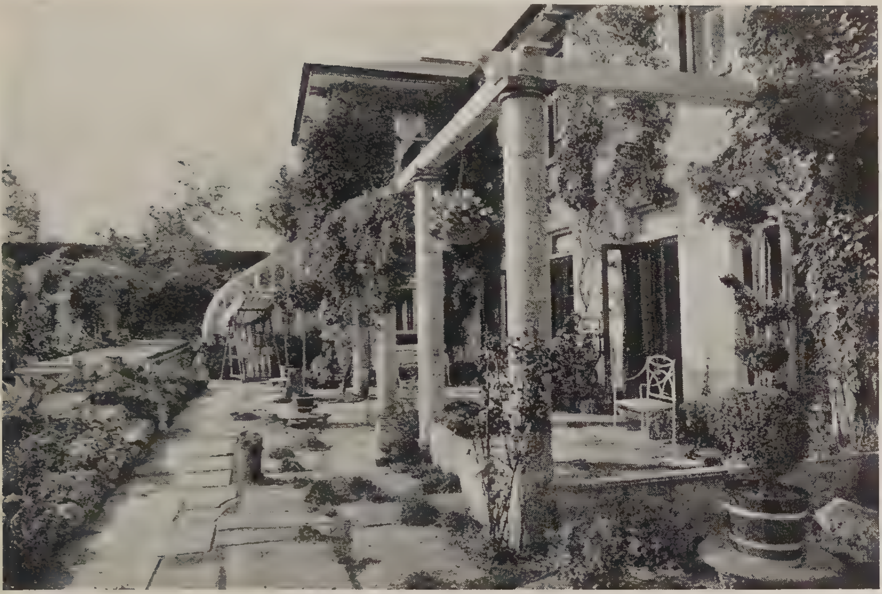

Fig. 675.—Concrete in the Garden.

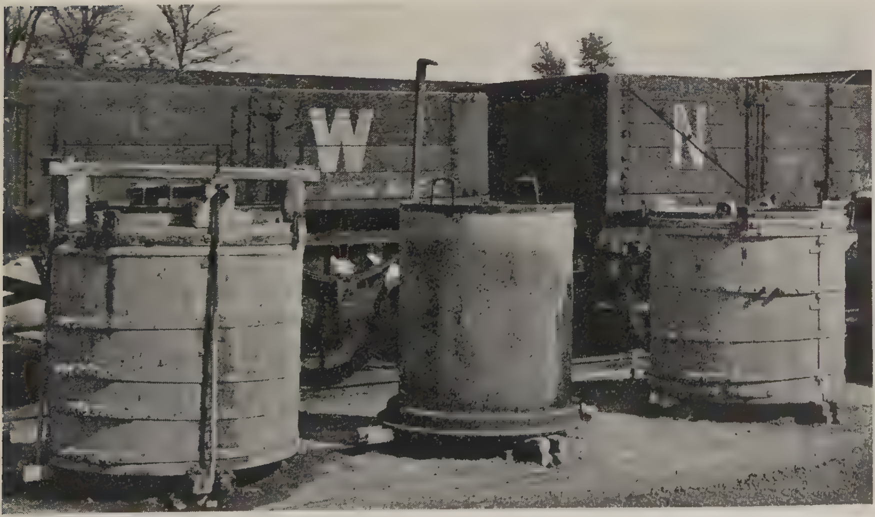

Fig. 676.—Pipe Moulds.

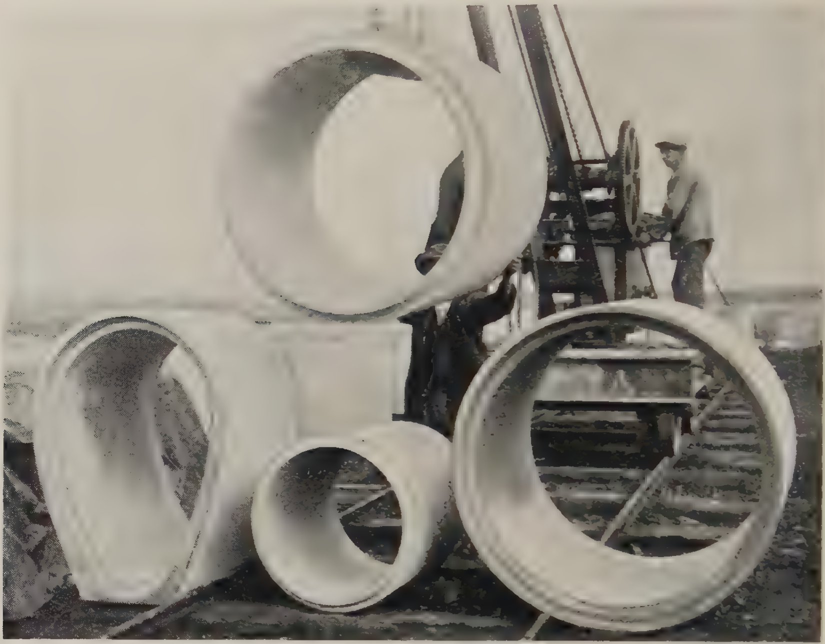

Fig. 677.—Concrete Pipes for Sheerness Main Sewerage.

same manner as the two-piece moulds but which rely upon the mould springing open slightly when the bolts are removed to allow of the mould

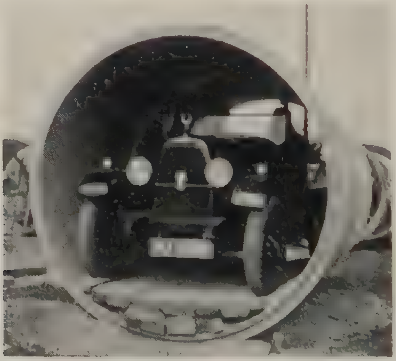

Fig. 678.—7 ft. Concrete Culvert Tubes.

being lifted from the pipe. The steel cores generally depend upon their ability to contract in diameter to permit their removal. There are

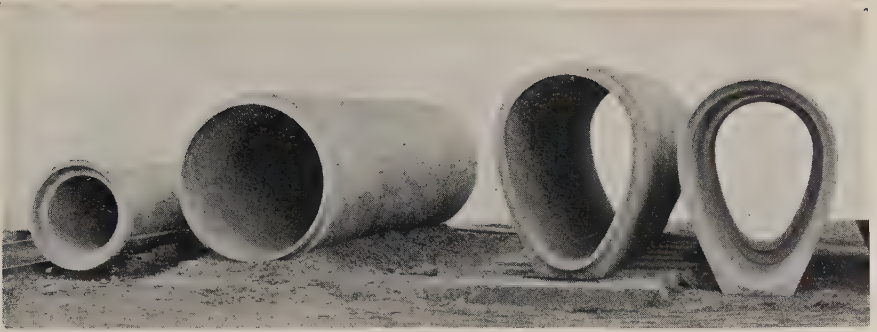

Fig. 679.—Concrete Tubes.

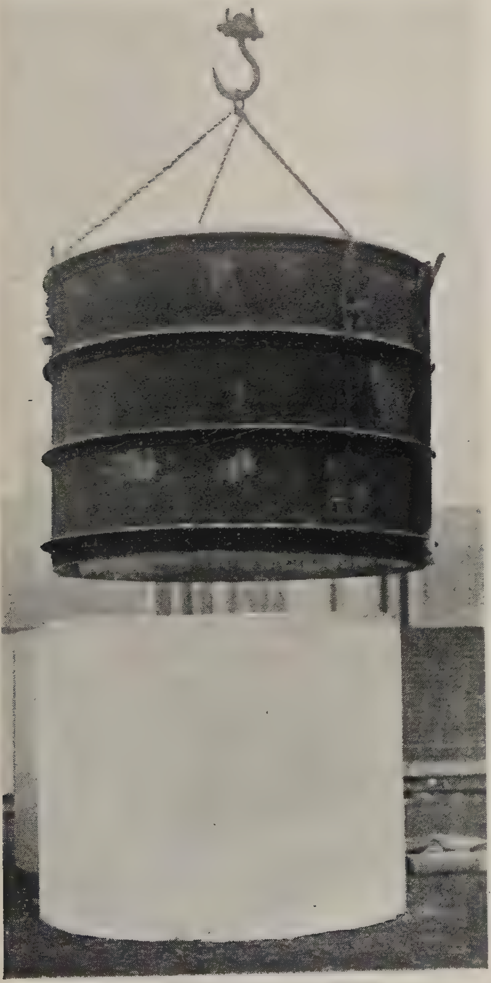

Fig. 680.—Stripping Mould from Concrete Tube.

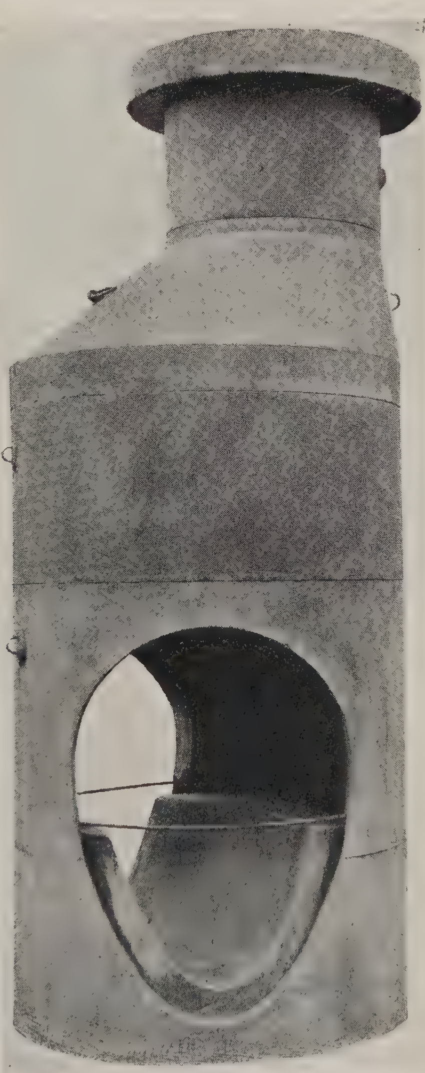

Fig. 681.—Concrete Manhole.

various methods of expanding these cores, such as driving taper-pieces into the open joint or the use of special expansion devices.

The whole of the pipe mould is made of steel. If the pipe is to have shaped ends, a metal ring of the desired shape is first placed on the pallet, and the core erected within this ring and expanded; the outer mould is then placed around the core and held in position to give the desired thickness of pipe-wall by the ring at the bottom and distance-pieces at the top. The concrete is placed and thoroughly tamped in layers of a few inches at a time. When the top of the mould is reached another ring is placed on the top of the mould and pressed down by a screw or by bolts passing through lugs on the top and bottom rings. If reinforcement is used, this takes the form of a mesh placed centrally between the core and mould before the concrete is placed.

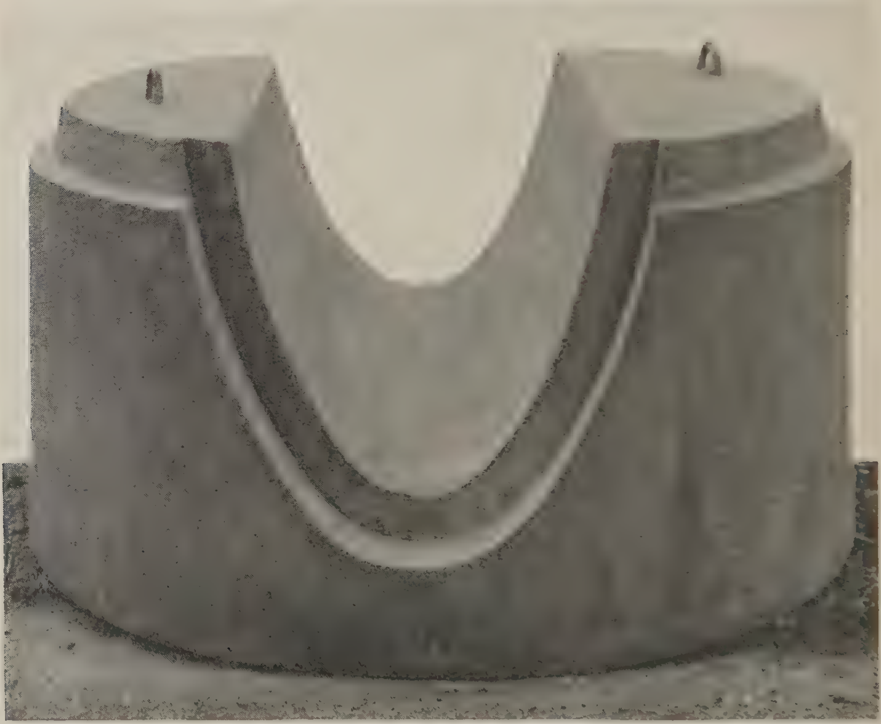

Fig. 682.—Concrete Invert Sections.

Manholes are made in the same manner as pipes; the same moulds are, in fact, used except for the taper-pieces. For the taper-pieces metal moulds and cores of the desired shape are used. Invert sections are made in moulds usually consisting of a circular steel outer casing and a wood core to give the invert shape.

In factories producing large quantities of concrete pipes in vertical moulds, automatic tamping devices are frequently used; one of these machines is shown in *Fig.* 683 in which the mould is rotated on the bed of the machine while the rods tamp the concrete with heavy blows in rapid succession.

In the "spun" pipe, which is consolidated by centrifugal force, the core is dispensed with. The outer moulds are arranged horizontally on an arrangement of bearer-wheels which, when in operation, cause the moulds to spin round at a speed sufficient to force the concrete against the mould and spread it evenly. The moulds have flanges at the ends of the same depth as the thickness of the wall of the pipe. The moulds are set spinning and concrete of a wet consistency fed into them until it reaches the top of the flanges. A metal rod is then passed through the pipe and held down against the flanges to remove surplus water. A feature of the con-

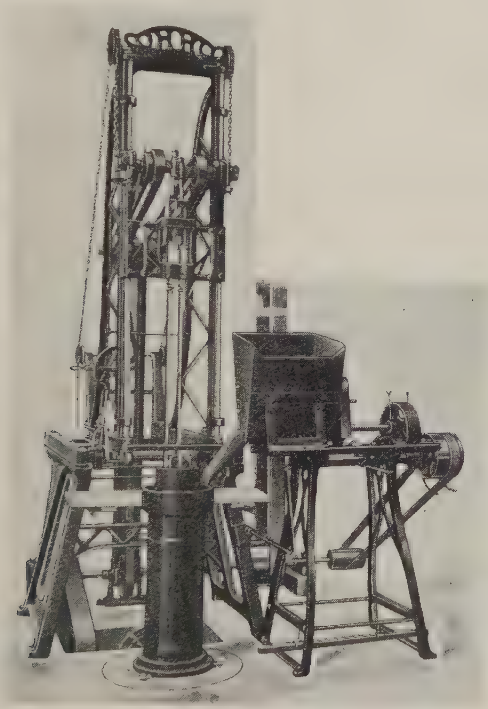

Fig. 683.—Pipe Machine.

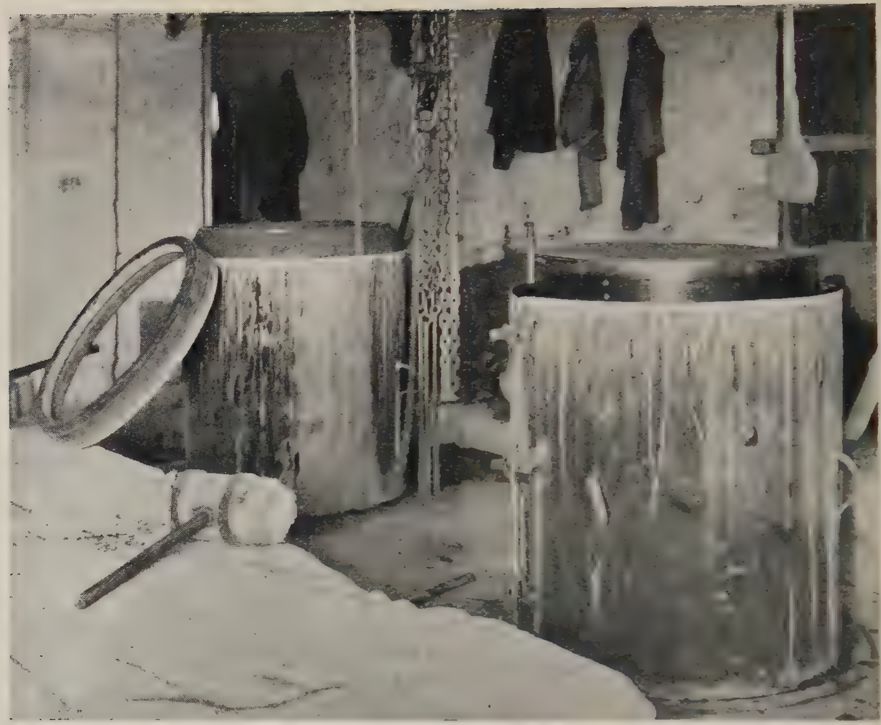

Fig. 684.—Concrete Pipe Moulds.

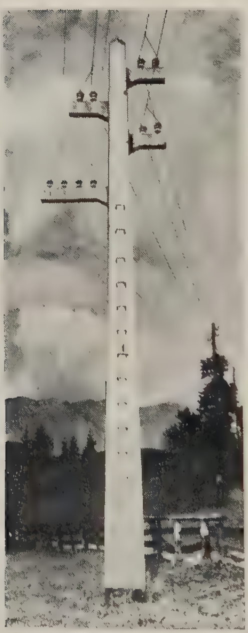

Fig. 685.

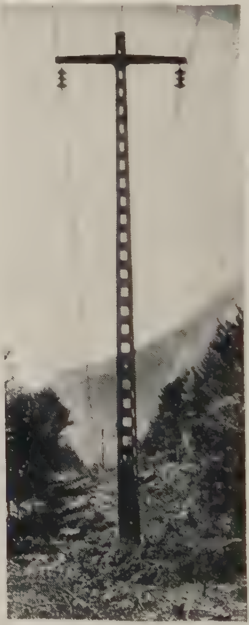

Fig. 686.

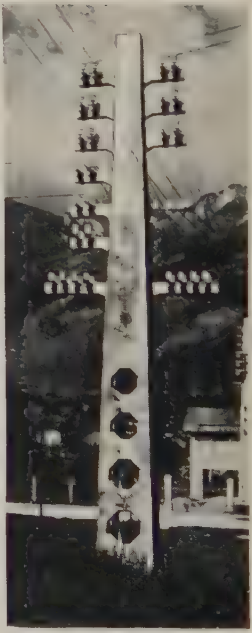

Fig. 687.

Concrete Transmission Poles.

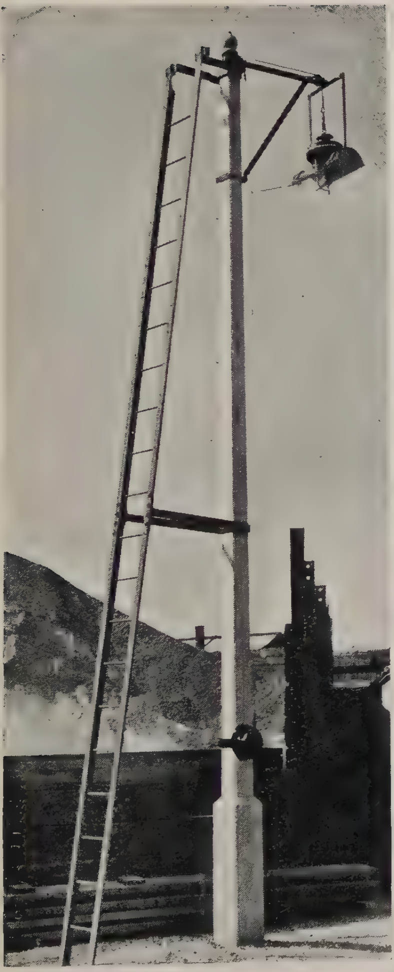

Fig. 688.—Concrete Lamp Standard.

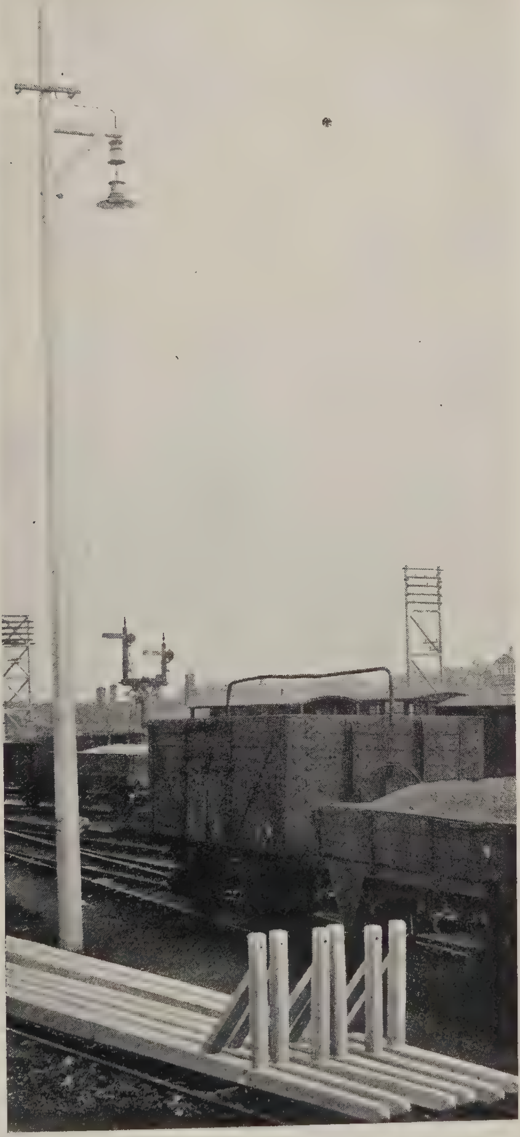

Fig. 689.—45-ft. Concrete Lighting Pole.

solidation of concrete by centrifugal force is the very dense and impervious nature of the concrete, and for this reason the process is eminently suitable for pipe manufacture. Centrifugal force is also made use of to make hollow concrete poles for transmission lines and other purposes.

Poles.—For the transmission of electric energy and for telegraph poles reinforced concrete is now used to a very large extent both in the form of ordinary pre-cast and centrifugally spun poles. Timber poles decay where they emerge from the ground and steel poles require painting or galvanising at intervals, whereas reinforced concrete does not suffer from either of these disadvantages.

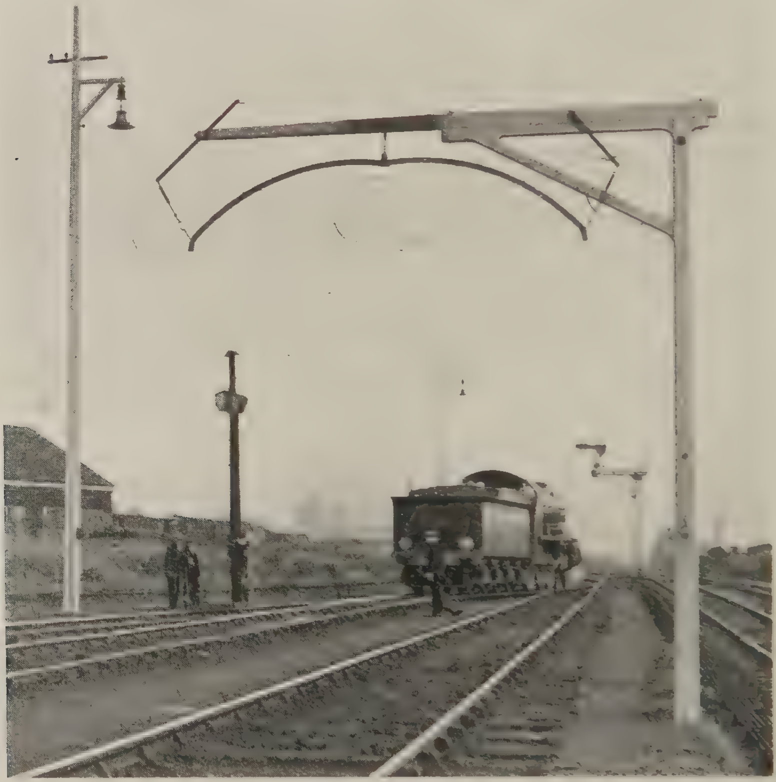

Fig. 690.—Loading Gauge in Concrete.

For lightly-loaded poles of medium height the solid square section reinforced with four main vertical bars and hooping is satisfactory, but poles for heavy loads and heights over 35 ft. are more easily handled if

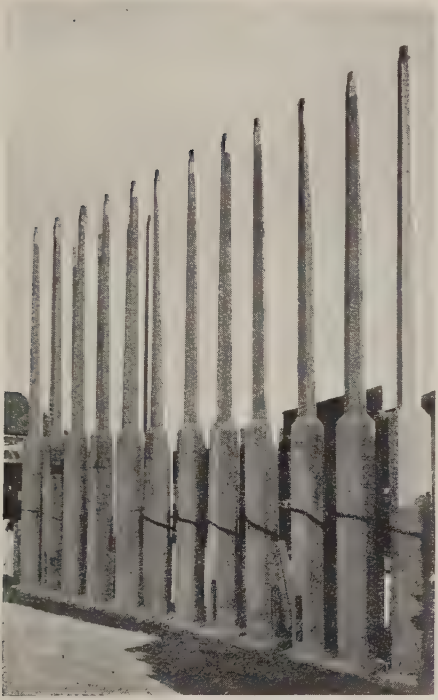

Fig. 691.—Concrete Lamp Standards.

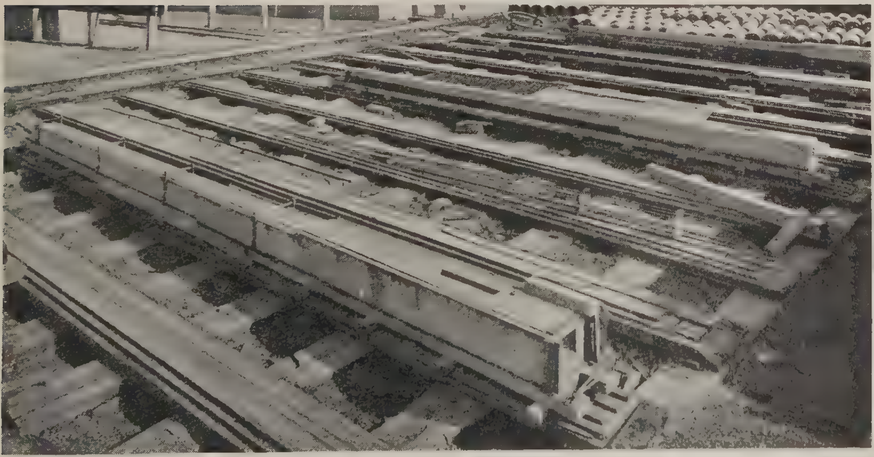

Fig. 692.—Lamp Post Moulds.

the section is made hollow or lightened as in the cross sections shown in *Fig.* 693. In this class of pole, stiffeners shown as 1 ft. 6 in. wide are introduced at intervals. Spun concrete poles have been used in pairs up to 95 ft. long and for spans of 600 ft., while single spans of 800 ft. and poles 65 ft. in height are usual on the Continent. The design of such poles is a simple matter once the loads and spans have been decided, since the pole merely acts as a vertical cantilever.

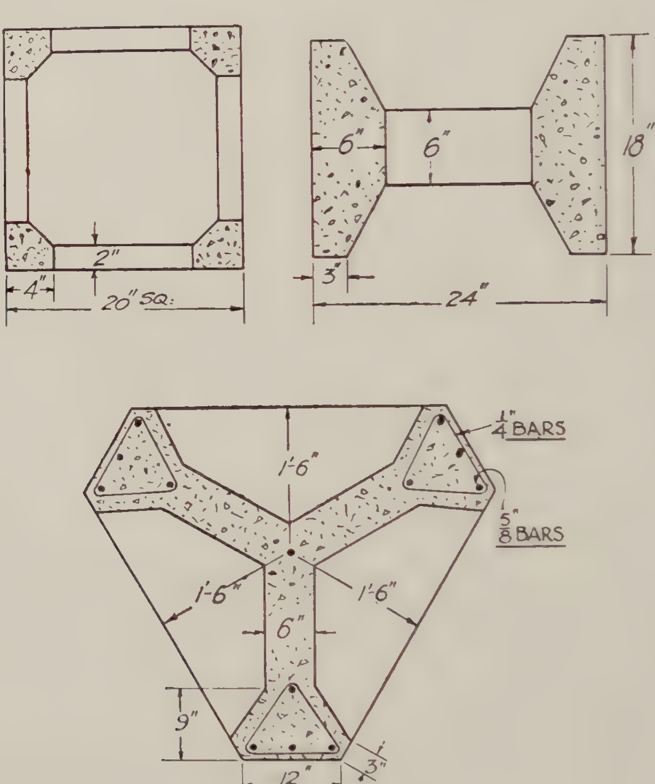

Fig. 693.

In determining the size of the concrete base for a pole care must be exercised to keep the lateral pressure on the ground within the safe limit for the particular soil in which the pole is erected.

Remarkable results have been found in testing reinforced concrete poles. A test on a spun pole 30 ft. long with 5 ft. of its length in the ground, designed with a factor of safety of 4 to take a working load of 1,210 lbs. near its top, gave the following results :

Loads Applied (lbs.).	Ratio of Applied Load to Working Load.	Elastic Deflection (inches).	Permanent Deflection (inches).
1,210	1·00	1·97	Nil
4,850	4·01	7·88	Nil
7,260	6·00	26·80	9·70

Even under four times the working load no permanent set took place and although the deflections were very high the poles went back to their original shapes when the load was removed.

In addition to transmission line poles, reinforced concrete has been used extensively for poles to carry lighter loads. Examples of these are telephone poles, signal masts, lamp standards, supports to railway loading gauges, etc. Such poles have a much longer life than timber and even at an increased first cost prove economical in the long run. Another attractive feature of concrete poles is that the maintenance cost is extremely low.

In order to secure good results in making concrete poles the requisites are adequate cover of concrete on the steel reinforcement, a fairly rich concrete, and careful curing to prevent the production of large shrinkage cracks. From 1 in. to 1½ in. cover is necessary in good-class work, and a concrete not leaner than 1 part of cement to 4 parts of aggregate. Cross-arms may be cast monolithic with the poles or holes may be boxed out for the bolts attaching the arms to the pole.

Light poles and posts are generally of solid square section, with or without chamfered corners. Some of the many types of light poles at present in use are illustrated in *Figs.* 685 to 694.

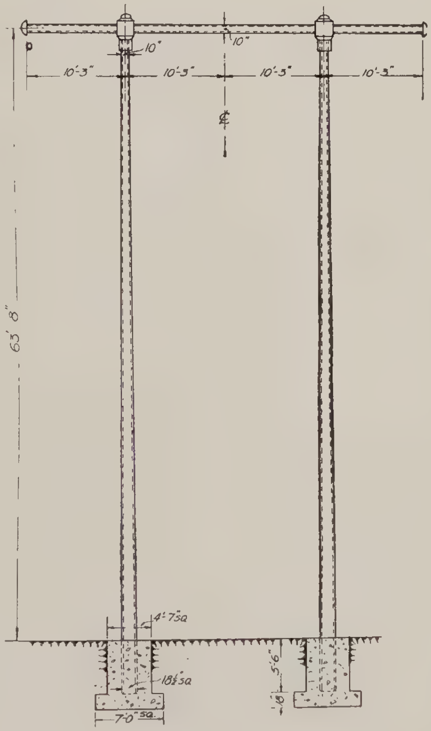

Fig. 694.

Posts.—Posts may be made singly in wood moulds made on the principles already indicated, or in "gang moulds" in which up to twelve posts are made at the same time. A typical post mould of this description is shown in *Fig.* 695. It will be noted that the divisions are placed to give the desired taper to the posts, and that bevel strips are used to chamfer the edges. The pyramid, rounded, or other shape top is obtained by shaped blocks of wood bolted through with the dividers ; for extensive production these shaped pieces are often made of cast iron.

For sign posts it is necessary to form slots or holes to take the arms, as described for poles.

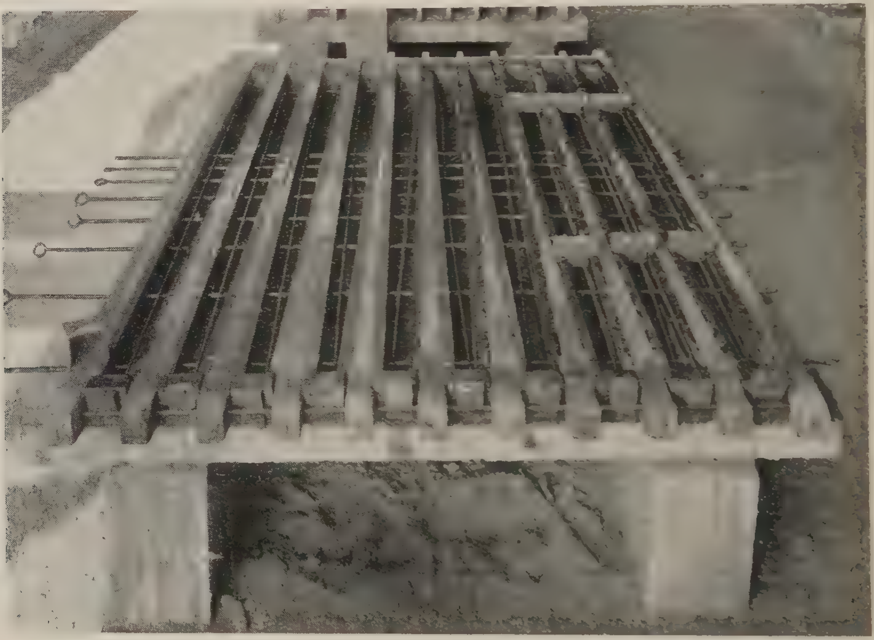

Fig. 695.—Fence Post Mould.

Lettering.—The lettering on concrete signposts, signboards, etc., may be cast at the same time as the arm or board, or separately. The latter method is generally preferred if the lettering is to be of a different colour, as in *Fig.* 706. If the lettering is to be sunk, reverse letters (see *Fig.* 704) are arranged in the bottom of the mould and the concrete placed around and over them. If the lettering is to be raised, the shape of the letters is cut in the bottom of the mould. Lettering cast separately is made in moulds, either wood or metal, as shown in *Fig.* 705, and grouted on to the signpost, name board, or where required. This lettering may, of course, be of any desired colour to show distinctly against the background, the ordinary procedure for making coloured concrete (see Part III) being followed.

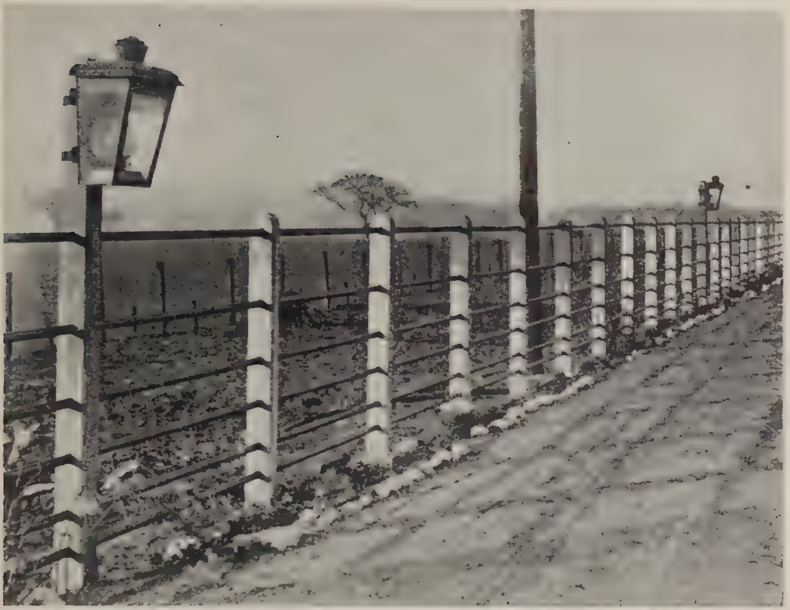

Fig. 696.—Concrete Fence Posts.

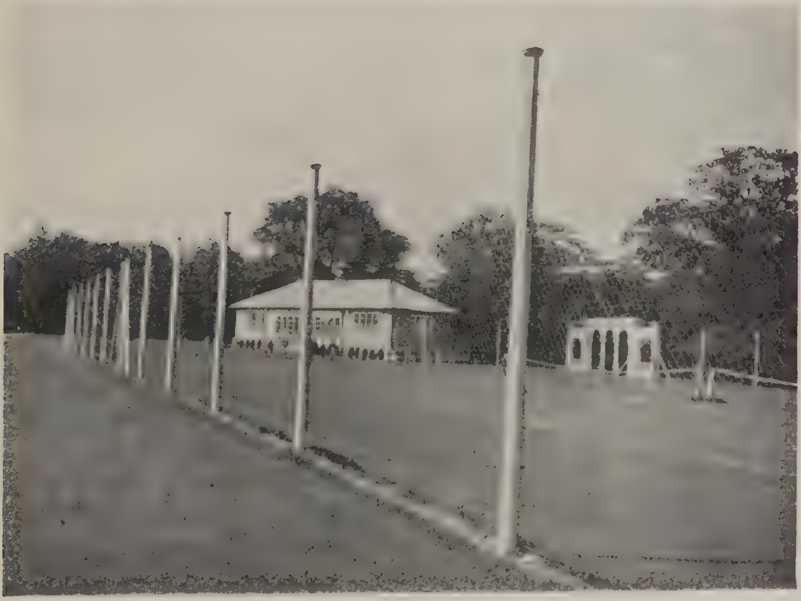

Fig. 697.—Concrete Tennis Surround Posts.

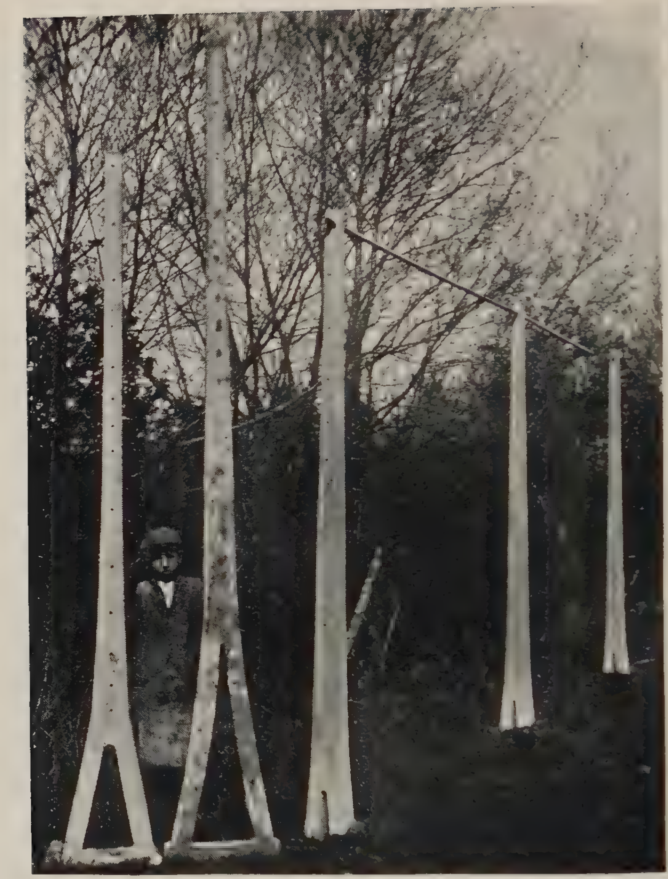

Fig. 698.—Concrete Posts for Rose Arches or Tennis Courts.

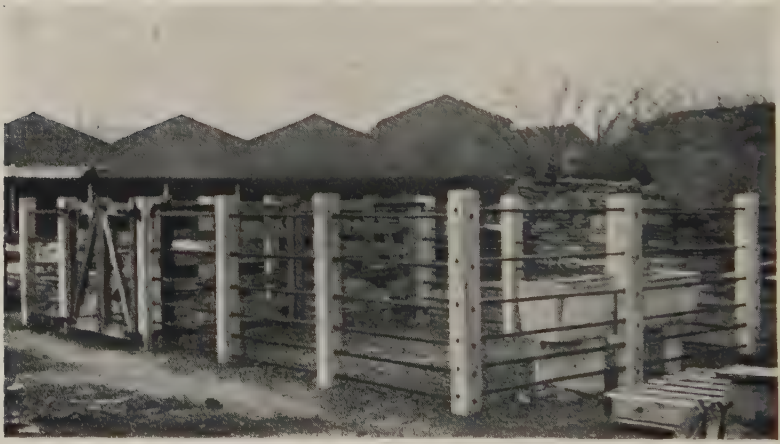

Fig. 699.—Concrete Cattle Pens.

Floor Tiles.—Patterned floor tiles are usually made in a pressure machine. A mould box is first fitted with thin metal dividers to form the pattern desired on the face of the tile, and different coloured concretes filled into the spaces. If desired the coloured concretes may be placed as a facing only, the remainder of the mould being filled with ordinary concrete. The metal dividers are then carefully lifted out and the moulds placed under a pressure machine (usually operated by hydraulic power), which thoroughly consolidates the tile and presses the different concretes against one another to form one homogeneous whole. Such floor tiles may be made to any design (see *Figs.* 709 and 710), and of any combination of colours.

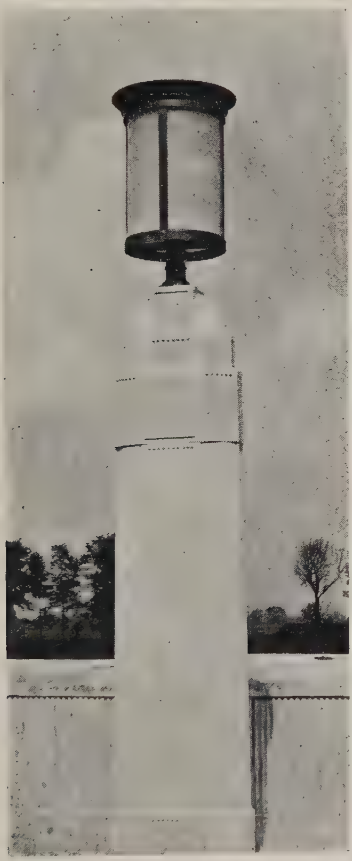

Fig. 700.—Concrete Lamp Standard.

Plain quarry tiles are also generally made in a pressure machine, but if only a few are needed they may be made in a wood tray which, following usual mould-making practice, is made so that the tiles can be lifted off on a pallet for curing. Simple machines of the type shown in *Fig.* 713 may also be used for the purpose.

Roofing Tiles.—Owing to the thinness of tiles no coarse aggregate can be used, so they are made of sand and cement only. The usual proportion is 1 part of Portland cement to 3 parts of sand. The sand must be of good quality and quite clean, as the presence of foreign matter or salt will invariably cause efflorescence.

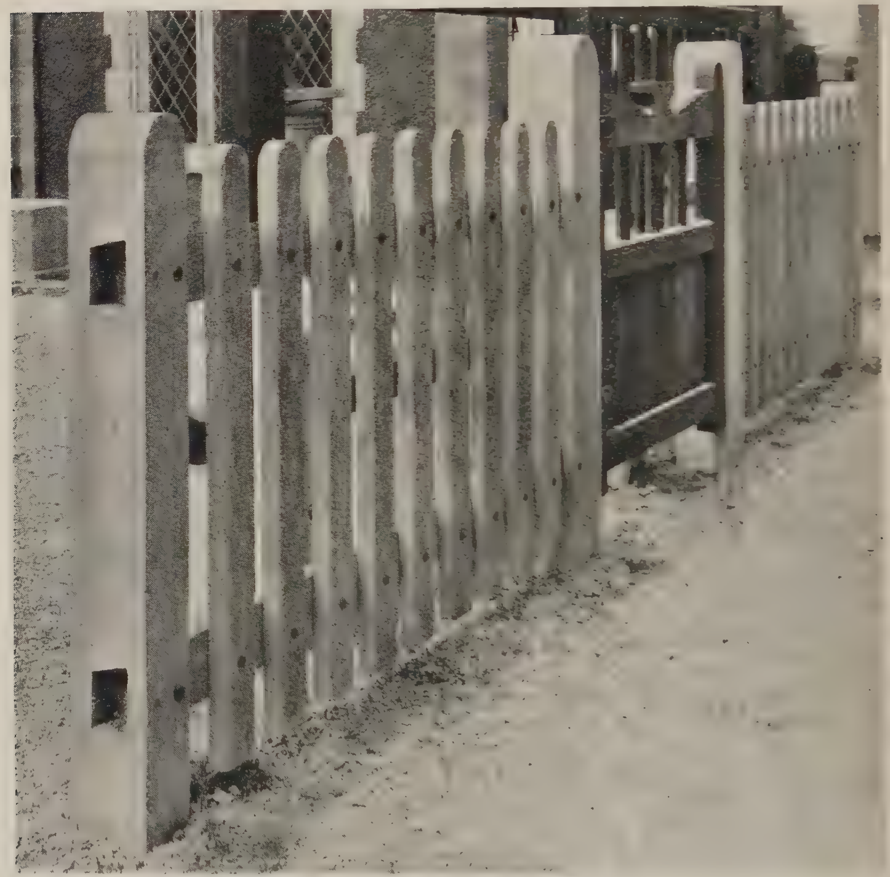

Fig. 701.—Concrete Fencing.

For practical reasons a fairly "dry" concrete must be used, as unless undue cost is to be incurred in pallets it must be possible to move the tiles

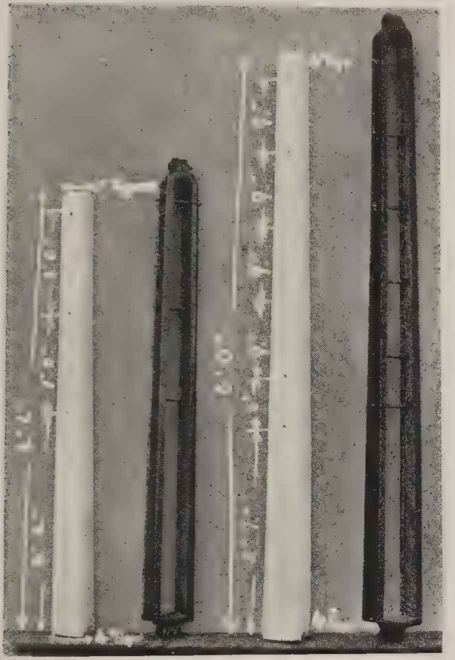

Fig. 702.—Metal Moulds for Posts.

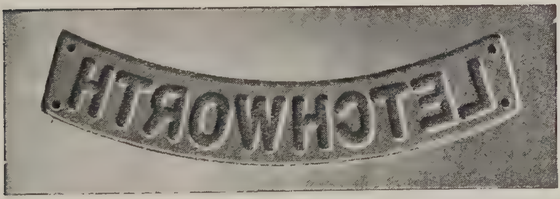
LETCHWORTH

Fig. 704.

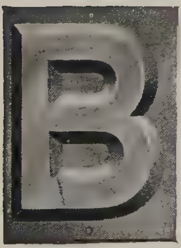

Fig. 703.

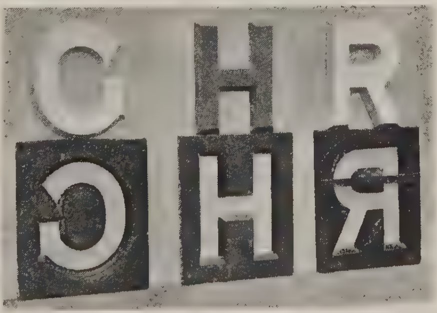

Fig 705.

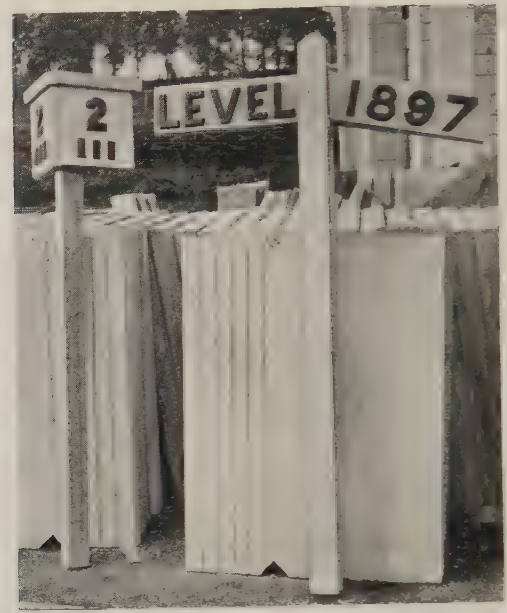

Fig. 706.—Concrete Mile Posts and Gradient Posts.

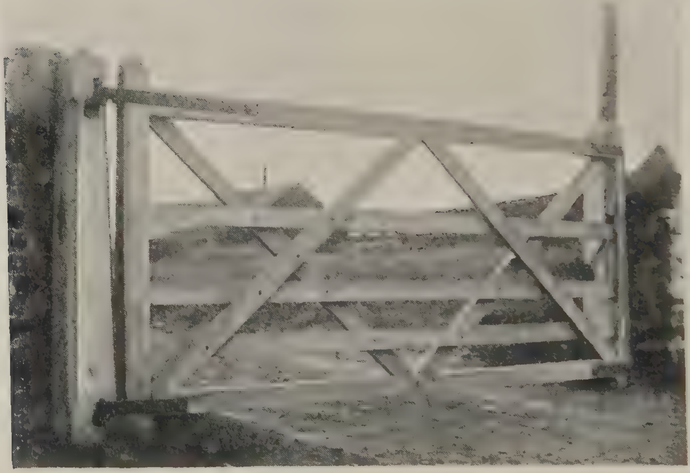

Fig. 707.—Concrete Gate and Posts.

soon after they are made. It is impossible to state the exact proportion of water to be added, as this will vary according to the quantity already held in the sand, but the right amount may readily be found from experience. In an endeavour to release pallets early, however, care must be taken as if insufficient water is present the tiles cannot reach any great degree of strength.

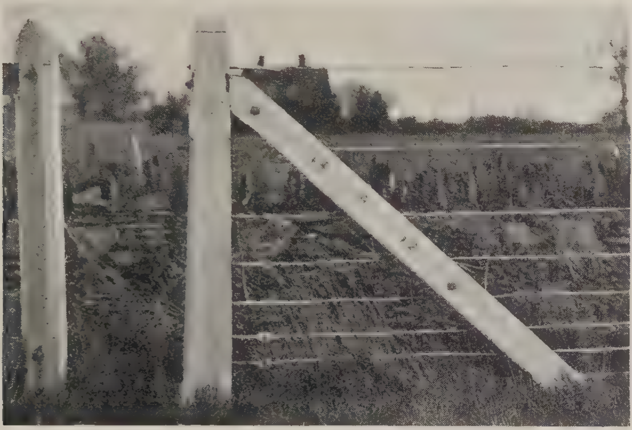
Fig. 708.—Concrete Straining Post.

The most common type of tile machine is shown in *Fig.* 713. The mortar is spread on the pallet forming the shape of the tile, which in this case is of the interlocking type. The top is levelled by a metal striker running on the sides of the mould, which tamps the mortar, levels it, and produces a tile of the correct thickness. Broseley tiles are made on similar machines, the only difference being the shape of the pallet and striker.

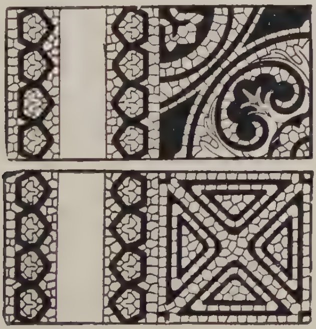
Fig. 709.

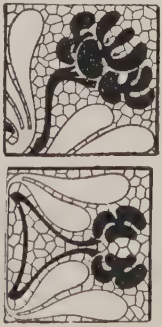
Fig. 710.

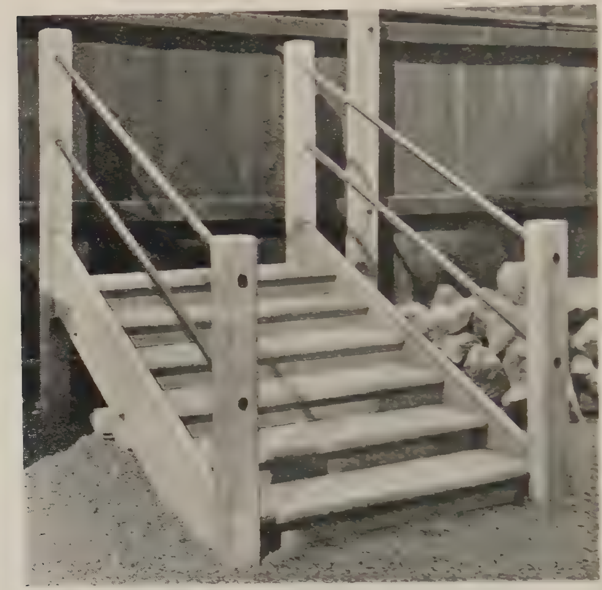

Fig. 711.—Concrete Stairs.

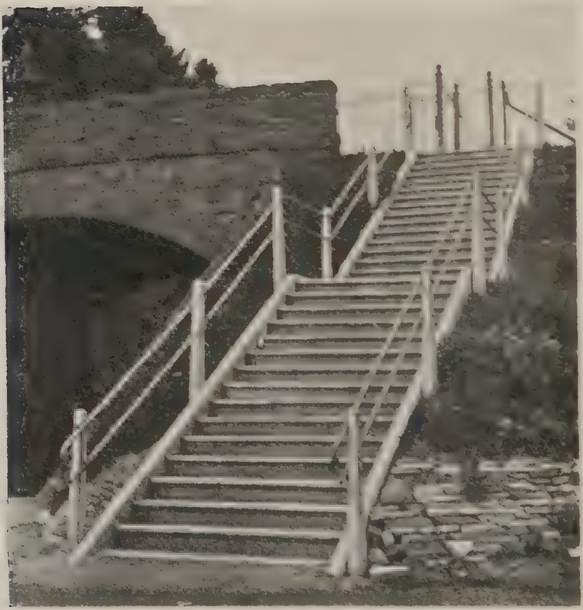

Fig. 712.—Concrete Stairs.

On the majority of these machines an output of 1,000 tiles a day can be maintained. When the tiles are smoothed off, the pallet is raised by the operation of a foot pedal, or by any other suitable method, and the tile removed on its pallet for curing.

Red is the colour most used for tiles, and this is obtained by colouring the concrete with red oxide. If preferred, coloured cements obtained ready-mixed from cement manufacturers may be used. Although red is most used, probably because of our familiarity with red clay tiles, concrete tiles may be made in any other colour, or by using special sands the superficial covering of colour may be dispensed with.

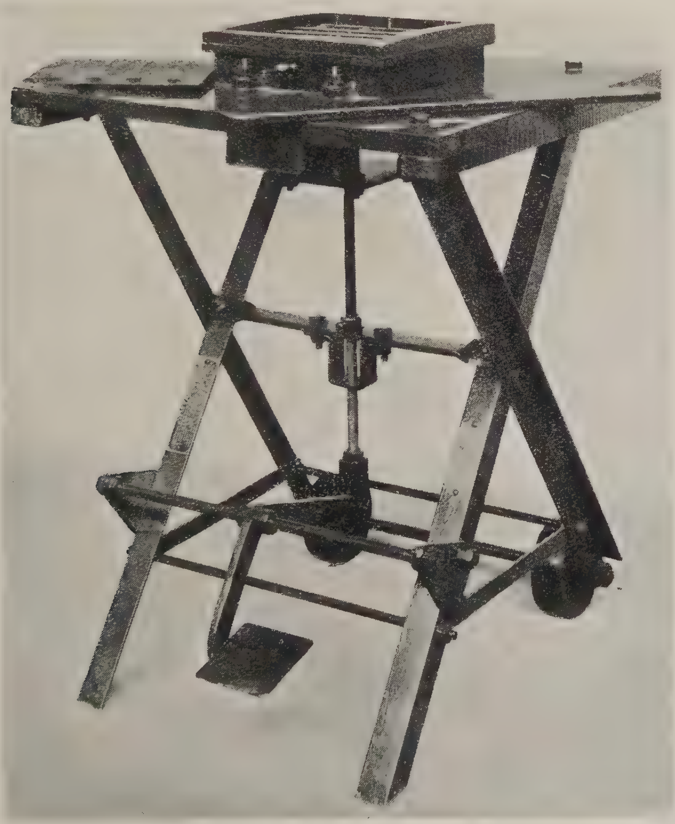

Fig. 713.—Roofing Tile Machine.

The colour may be used on the surface of the tile only, or throughout the mix. If the colour is to be on the surface only a good method is to

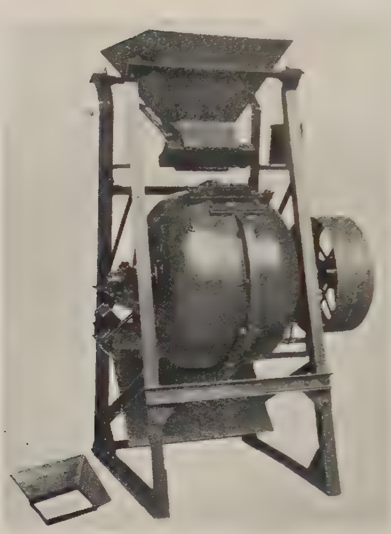

Fig. 714.—Colour Mill.

grind dry equal quantities of cement and colour (preferably in a colour mill, see *Fig.* 714), then add a proportion of sand equal to the total volume of cement and colour, and mix dry, then add water until a creamy consistency is obtained, and thoroughly mixed again. The object of this is to ensure that the colour throughout bonds with the cement, and to prevent it dusting off as it is likely to do if applied as a colour wash only. The cement and sand ensure that the colour becomes an integral part of the tile. For some purposes it is necessary to blend different colours. As soon as the surface of the tile has been smoothed off with the striker, the colour is put on with a brush and the striker again run over the surface to press the colour firmly into the surface. Care must be taken not to press it below the surface.

Fig. 715.—House Roofed with Concrete Tiles.

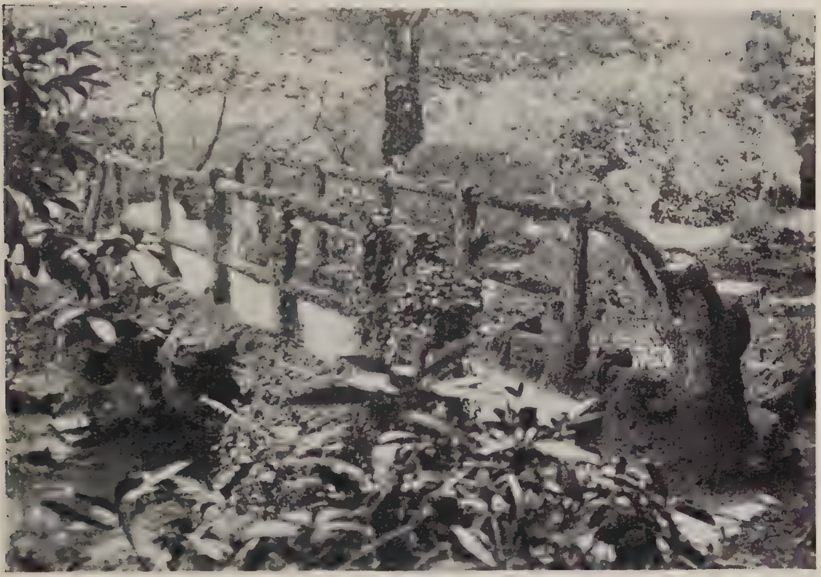

Fig. 716.—Concrete Bridge in Okehampton Park.

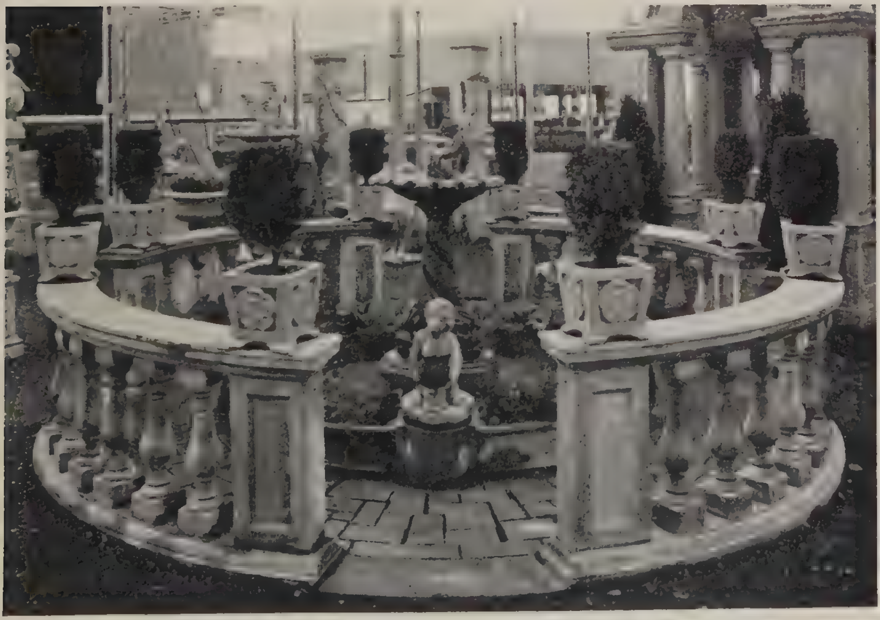

Fig. 717.—Concrete Garden Ornaments.

In another method the cement colour and fine sand are mixed dry and sprinkled on the wet tile through a sieve, known as a "shaker." If a sand-face effect is desired, this is obtained by sprinkling fine sand on the finished tile after the colour has been applied.

A rough-textured tile is generally made by dashing water on the surface from a brush. A wooden striker made end grain and left slightly rough will give a good effect. When random or variegated colours are made, the operator has supplies of each of the necessary colours beside him; it is advisable first to make a specimen which he can keep in view during the manufacture of the whole batch.

When a large batch of tiles is required of uniform colour, a note must be made of the exact proportion of colour used on the first batch to be made in order that this may be maintained throughout. Any variation in the proportioning of the colour will result in batches of tiles of different shades. It will often be found, however, that architects prefer slight variations in colour.

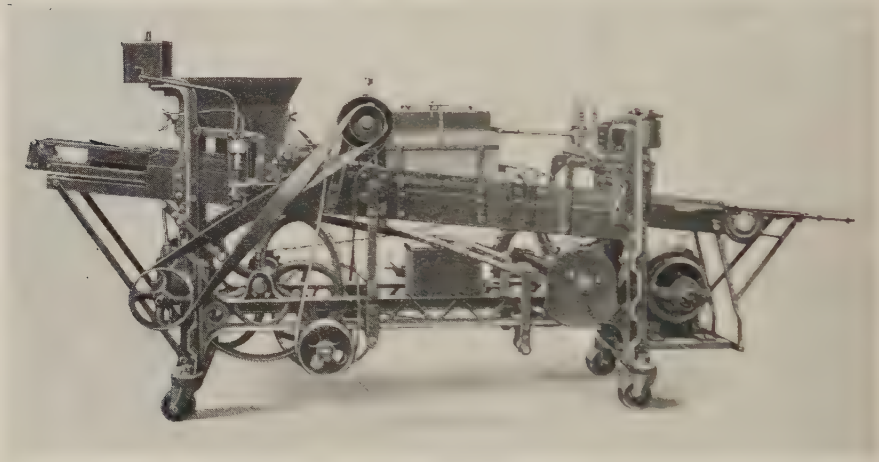

Fig. 718.—Tile Machine.

When the tiles are to be coloured all through, cement and colour in equal proportions are thoroughly mixed dry and then added to the remainder of the cement and sand in an ordinary mixer. The method of manufacture is the same, except that there is, of course, no need to brush and sprinkle the surface.

Tiles may be cured by the ordinary methods of curing concrete, namely, storing them under cover for a day or two according to weather conditions and then storing out of doors with occasional sprinkling for three or four weeks, but perhaps the best and simplest way in a temperate climate is to immerse them for five minutes the day after they are made ; if this is done and the tiles protected from sun and drying winds and frost no further watering is necessary.

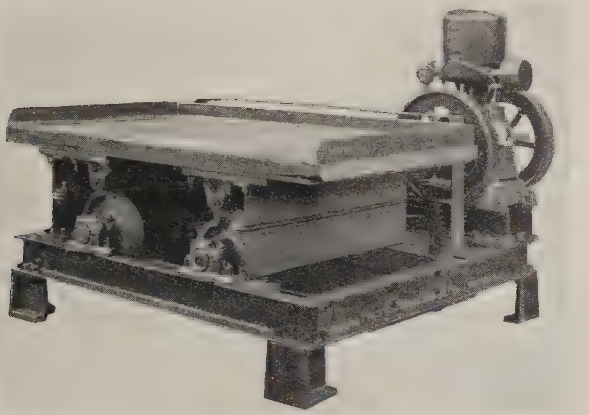

Fig. 719.

During the first twenty-four hours the tiles should be kept on their pallets. The next day they will probably be strong enough to remove from the pallets and stack on edge, while on the third day the racks containing the tiles may be taken into the open.

Machines for the mass production of roofing tiles are also available. In the type shown in *Fig.* 718, mortar is fed into the hopper to the left which automatically feeds on to an endless tray moving from left to right in the photograph. The material passes under a roller which presses it to the desired thickness, colour is shaken on, and an automatic guillotine cuts the tiles to the desired length, during the passage of the concrete through the machine, and the tiles are lifted off at the right-hand end of the machine.

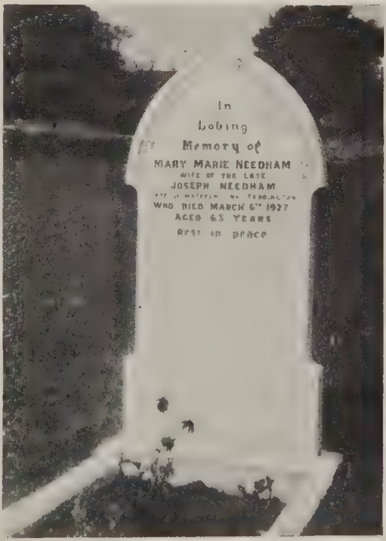
In
Loving
Memory of
MARY MARIE NEEDHAM
WIFE OF THE LATE
JOSEPH NEEDHAM
WHO DIED MARCH 6TH 1927
AGED 63 YEARS
Rest in peace

Fig. 720.—Concrete Headstone and Kerbing.

Vibration

A comparatively recent development in the manufacture of concrete products is mechanical consolidation by vibration. The usual type of vibrator consists of a table which is actuated by rockers or cams so that it is forcibly vibrated with an upwards and sideways motion. The effects of vibration are to cause the excess water and air to rise to the surface and to compact the concrete more thoroughly than can usually be done by hand. The series of jolts delivered in rapid succession causes the particles in the concrete to slip into place to form a very dense mass which is hard enough to resist pressure of the thumb very shortly after it has been vibrated. As excess water and any entrapped air are forced to the surface, a face comparatively free from pitting due to these causes is produced. A typical vibrating table is shown in *Fig.* 719.

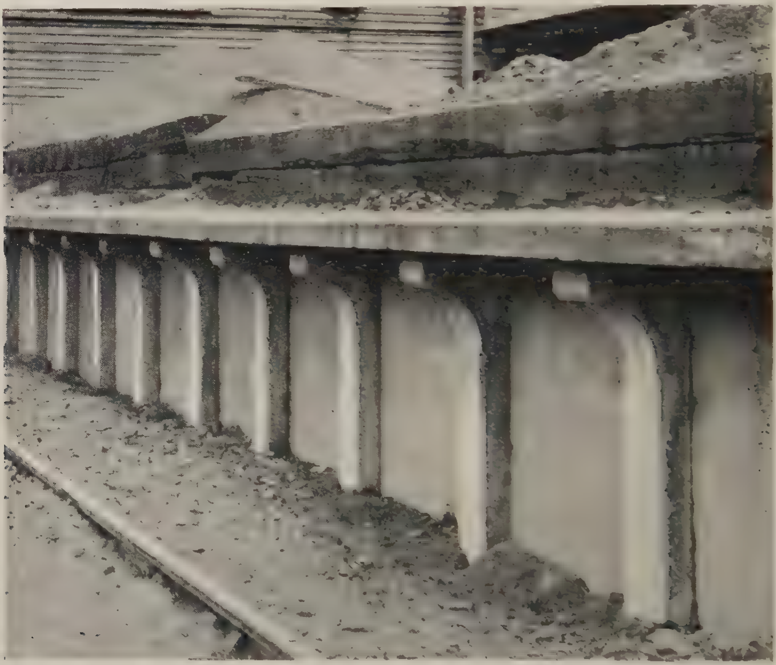

Fig. 721.—Concrete Platform Walling.

Curing

Special precautions must be taken during the period required for precast concrete goods to harden due to the fact that the moulds are stripped, and this protection removed, earlier than in the case of *in situ* concrete.

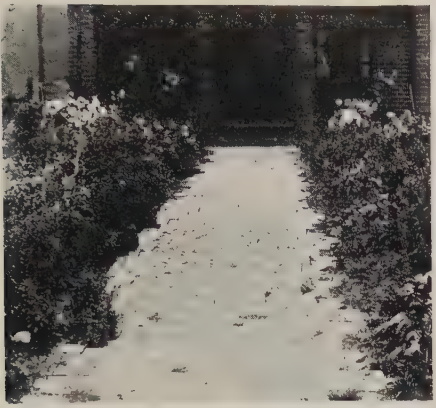

Fig. 722.—Concrete Garden Paving.

If made of ordinary Portland cement the goods should be protected from extremes of temperature for at least three weeks : covering them to ward

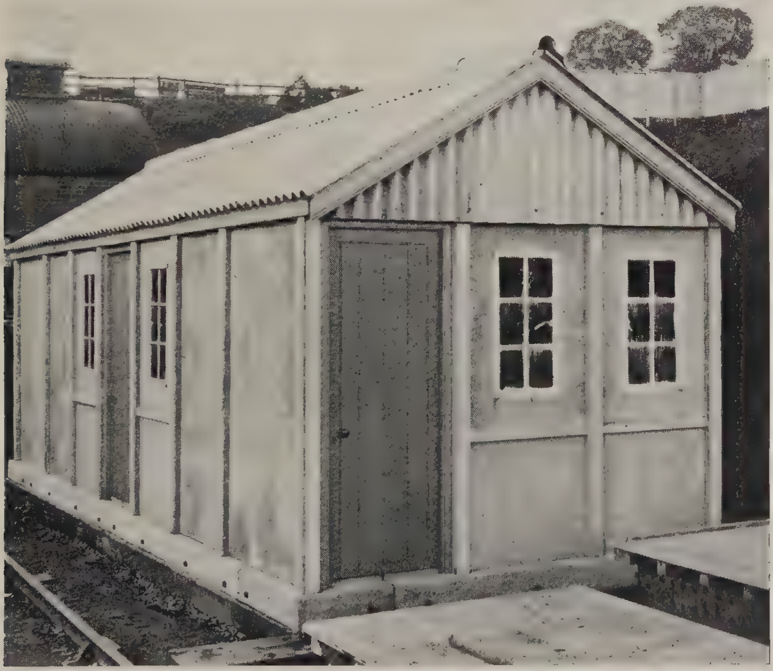

Fig. 723.—Sectional Concrete Building.

off frost during cold weather; protecting them from the heat of the sun and drying winds in summer; and sprinkling to keep them moist when the rainfall is not sufficient for this purpose. The period of protection may be reduced to four days if "Ferrocrete" is used, and 12 hours if "Lightning" brand aluminous cement is used.

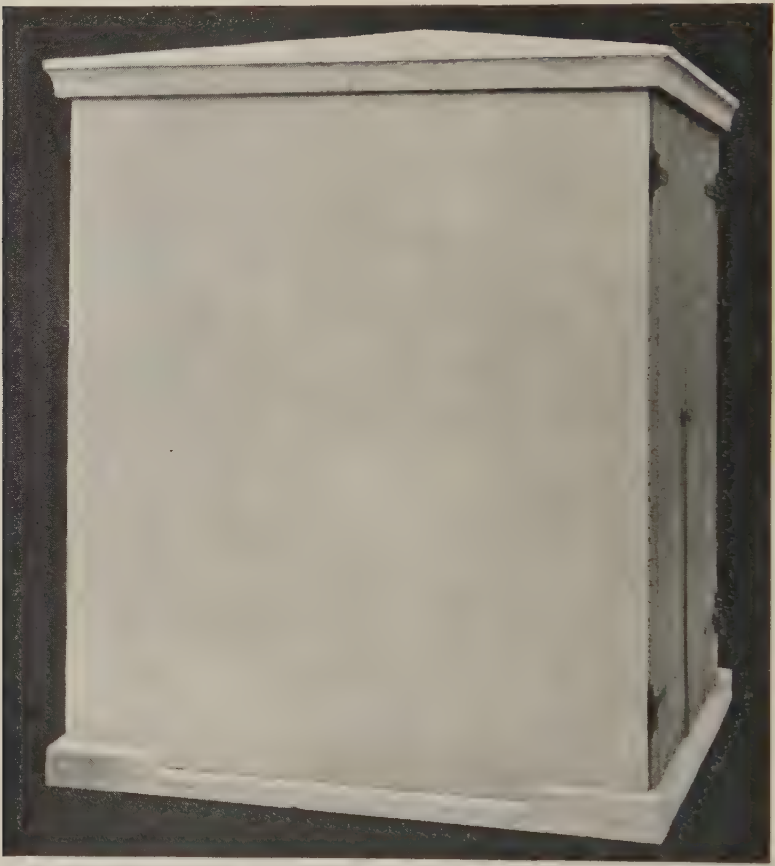

Fig. 724.—Sectional Concrete Store.

Sacking, tarpaulins, sand, and similar materials are suitable for protection from frost, sun, and drying winds, but if only outdoor storage is available it is advisable to cease manufacture during a long spell of freezing weather. When watering during dry weather it is necessary to ensure that all faces of the products are thoroughly wetted.

During cold weather it is advisable to keep the factory warm, either by hot-water pipes or by braziers. If coke braziers are used it is desirable to keep pans of water over them to prevent a dry heat which is detrimental to the setting of concrete.

STANDARD SPECIFICATIONS

A newly-formed body known as the Cast Concrete Products Associations, and which includes within its membership many of the leading cast stone and concrete products manufacturers, has as one of its principal objects the provision of standard specifications for various types of pre-cast concrete goods. Standard specifications issued by the British Engineering Standards Association are already available for concrete paving flags and concrete kerb and channel, and are generally used by local authorities.

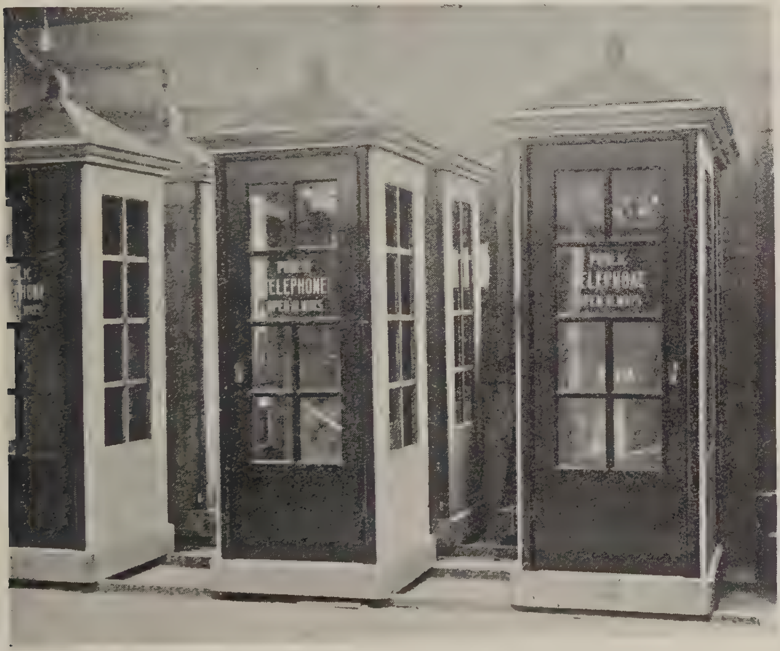

Fig. 725.—Concrete Telephone Kiosks.

Kerb and Channel.—The B.E.S.A. Standard Specification for kerb and channel gives the following strength requirements for these goods:

The test for transverse strength is as follows: The kerb or channel is to be supported on bearers ½ in. wide on the face, parallel to each other and 2 ft. 6 in. apart. The greatest width of wearing face in each case is to be uppermost. The load is to be applied on a space 2 ft. wide in the centre of the kerb or channel, and extending right across it parallel to the bearers. The following strengths must be reached in the case of various sections :

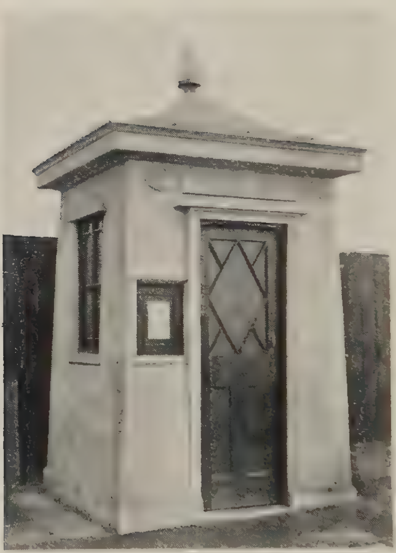

Fig. 726.—Concrete Police Box.

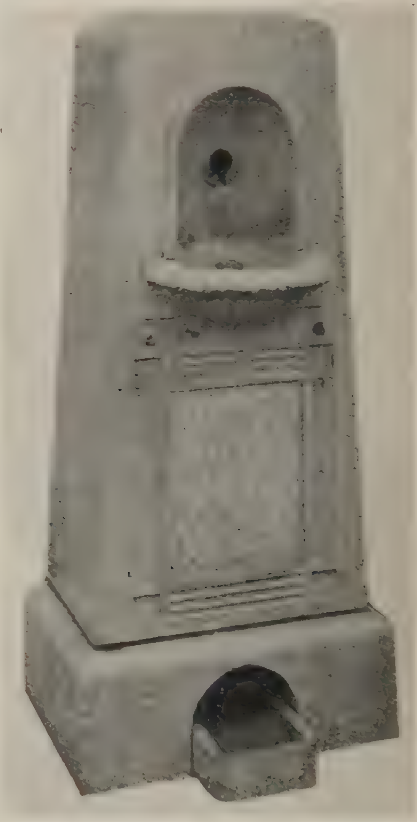

Fig. 727.—Concrete Drinking Fountain.

RECTANGULAR KERBS

Size of kerb.	Lbs. per inch of width.
12 in. by 6 in.	400
10 in. by 5 in.	280
10 in. by 4 in.	180

BATTERED KERBS

Size of kerb.	Lbs. per inch of width.
12 in. by 6 in.	330
10 in. by 5 in.	220

For the absorption test sample pieces of kerb and channel about 1 ft. run, having two moulded and two cut edges, shall, after being thoroughly dried to a constant weight at a temperature not exceeding 100 deg. F., and weighed, be submerged in water for a period of at least 48 hours. On being removed from the water they shall immediately be wiped with a cloth and be again weighed. The increase in weight of each sample by absorption of water shall not exceed 2 per cent.

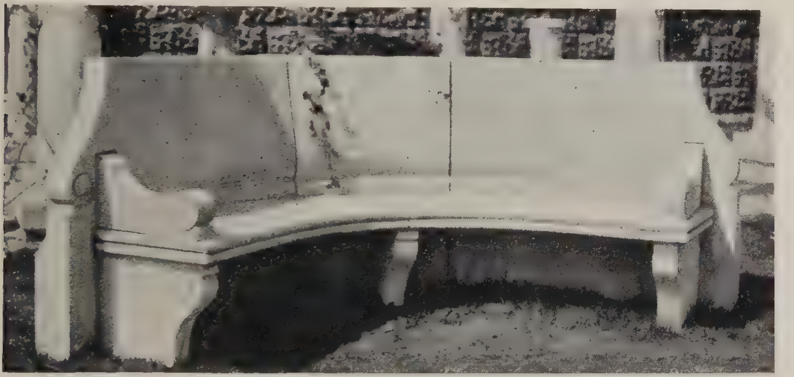

Fig. 728.—Concrete Garden Seat.

The products dried to a constant weight as stated above must have a weight of not less than 140 lbs. per cubic foot.

Paving Flags.—The 1929 Standard Specification for Paving Flags of the British Engineering Standards Association stipulates that flags made of ordinary Portland cement concrete shall be not leaner than 1 : 3, and that they shall not be delivered to a customer until they have been made at least 24 weeks. If rapid-hardening Portland cement is used, however, a leaner mix is permitted by calculating the cement at 80 lbs. per cubic foot instead of 90 lbs. in the case of ordinary Portland cement. Also, when rapid-hardening Portland cement is used the flags may be delivered four weeks after manufacture instead of 24 weeks. All flags made with rapid-hardening Portland cement are to have the letter R marked on the back.

Standard sizes are fixed. These are all 2 ft. in one direction and range from 1 ft. 6 in. to 3 ft. in the other direction : thicknesses are 2 in. and

2½ in. The dry weight of concrete is not to be less than 140 lbs. per cubic foot. Aggregate is to be ⅜ in. or less in size.

The test for transverse strength provides that a load be applied not exceeding 112 lbs. per 10 seconds. Flags 2 in. thick must support for one minute a load of 1,120 lbs. for each foot of width and 2½-in. flags 1,736 lbs. for each foot of width.

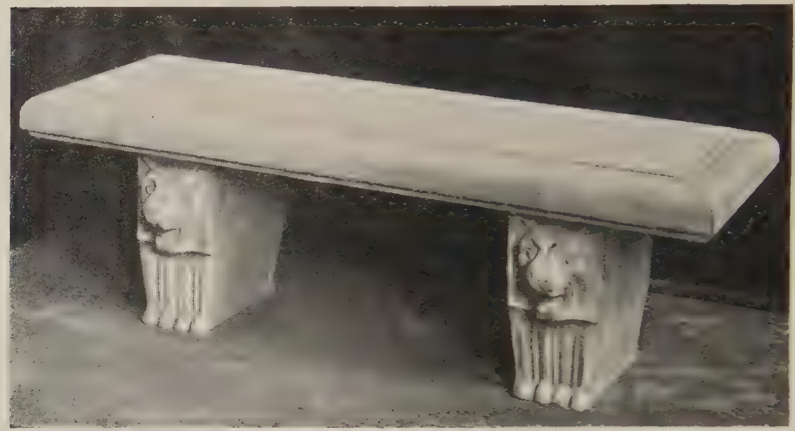

Fig. 729.—Concrete Garden Seat.

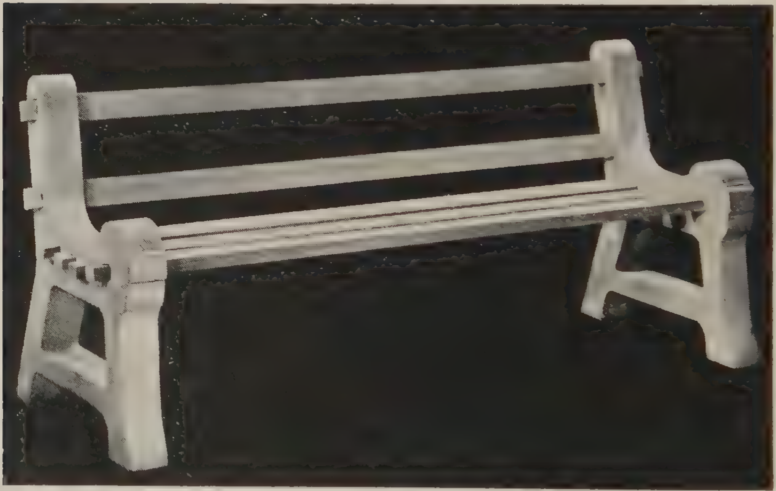

Fig. 730.—Concrete Garden Seat.

For the rate of wear test, samples 2 ft. by 1 ft. are tested by an apparatus comprising a rectangular container with solid ends secured through their centres at a distance 22 in. apart to a steel shaft 1½ in. in diameter, and with one or more of its sides having openings 22 in. by 10 in.; the shaft projects from the ends of the container and is supported on bearings arranged so as to maintain the shaft horizontal and allow it to revolve freely. After being dried and weighed the samples are fixed in position with their wearing faces inwards. One thousand steel or iron balls are placed in the container, which is revolved for 24 hours in each direction at a speed of 60 revolutions a minute. Under this test the wear must be uniform, and must not result in a loss of weight exceeding 3 lbs.

The rate of absorption is limited to 1½ per cent. increase in weight of a sample 18 in. square after submersion for a period of 48 hours.

PART IX

THEORY OF REINFORCED CONCRETE

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THEORY OF REINFORCED CONCRETE

Concrete is very strong in compression but weak in tension. This means that a slab of concrete on a firm, smooth foundation will support a very great weight without cracking or crushing, but if the slab is raised and laid across supports at each end only, and the load applied in the centre of the span, it will break under a comparatively small load. In other words, concrete will resist very high compression but it has very small resistance to a load that tends to bend it. From very early times almost up to the end of the nineteenth century, there was no known method of strengthening concrete so that it would resist bending as well as it would resist compression, with the result that it was used only for such purposes as caused it to be in compression only, such as foundations and arches.

In the latter half of the nineteenth century, however, steel was invented, a material which is very strong in tension, and one which will resist to a high degree the application of a load or force that tends to bend it. Steel has just the property that is lacking in concrete, and it was soon discovered that the two materials could be combined to produce a composite structure of steel and concrete that would be equally strong in tension and compression. It is this combination of steel and concrete that is known as "reinforced concrete," and which has revolutionised building construction by making available a material with all the strength of concrete to resist compression but with the additional advantages that it is as strong as steel in resisting bending, while it is at the same time considerably cheaper than plain steel, and, as stated elsewhere in this volume, the cost of frequent painting necessary to preserve bare steel is saved.

No attempt is to be made here to give full information on the design of reinforced concrete, as this is a highly technical subject on which the advice of specialists must be taken, but the following notes on the underlying principles of reinforced concrete should be understood by all engaged in the execution of such work.

In order to get a clear conception of the principles of bending and the manner in which slabs and beams transfer their loads to their supports, it is necessary to understand what is meant by the terms Load, Reaction, Stress, Strain, Bending Moment and Shearing Force.

Load

Generally speaking, the term load comprises:

(*a*) The dead weight of the member or part of the structure under consideration; and

(*b*) The superimposed or external weight requiring support.

The dead load of the member means the actual weight of the material composing that member. As an example, if a concrete beam 12 in. deep and 8 in. wide is resting on two walls which are 15 ft. apart, the beam must have sufficient strength to carry its own weight across this span, because the weight of the beam constitutes a load which is unsupported except by the walls at the ends. This may not appear to be a serious point, but the actual weight of the beam forms part of the total load to be carried and must be added to the superimposed load to arrive at the requirements of strength.

The superimposed load means the weight, other than its own dead weight, which the part of the structure has to carry. The amount of this will vary according to circumstances. In the case of a floor slab the superimposed load will be the weight to be placed on the slab when the building is in use, and this if not definitely specified beforehand by the building owner, is generally assumed by the designer in accordance with regulations or rules laid down. The total load that has to be provided for in the case of a floor slab is therefore the weight of the materials used added to the weight that will be carried by the floor.

Sometimes the load to be carried is concentrated in one point, as, for example, when the end of one beam rests on another or where an upper column is supported by a beam without another column immediately below.

The two methods of loading to be provided for are known as "concentrated" and "distributed" loads.

A load or force in constructional work is always tending to break the part of the structure that is called upon to offer resistance, and generally speaking this tendency, if not resisted, would result in collapse of a part or the whole of the building. This tendency of the load is resisted by the supports at the ends of the beam, which keep the beam in position.

Strain is the distortion or alteration in shape produced by a force or action which brings into play the resistance of a body.

When a load or a force is applied to a piece of material it produces a strain or an alteration in the shape, and this calls forth a resistance in the material itself, which means that the material is subject to a stress. In other words, the strength or resistance of the material which comes into action under a load or force causes the stress to occur. The kinds of stress that require to be considered in reinforced concrete work generally are,

(*a*) Tension,

(*b*) Compression, and

(*c*) Shearing.

Tension

Tension stress is that caused by stretching a material.

Compression

This is the stress caused when a material is under the action of a load or force tending to crush it.

In a simply reinforced concrete beam the compression resistance is provided by the concrete.

Shearing

The third and last kind of stress mentioned is shearing. This can be defined as a cutting or sliding action, and when failure occurs the material is separated into two or more portions by the sliding of one section, either horizontally or vertically on the adjoining section. In the case of uniformly distributed loads the maximum shear will be equal to the reaction at the support, but will gradually diminish to the centre of the span where it is nil. As a provision against the failure of a reinforced concrete beam by shearing, stirrups or cranked bars are introduced, and these are spaced according to the total stress at given sections.

Bending Moments

A bending moment is a bending amount. The term " moment " is used in calculations to express the product given by multiplying weights or pressures by distances as distinct from a simple amount of weight alone.

The bending tendency is caused by the opposition of the load and the reaction, as these represent forces acting in opposite directions ; the beam is the lever, between the two, which is called upon to carry the load to the support where the two forces can neutralise each other to produce equilibrium. A simple example is given in *Fig.* 731 where a beam having a span of 120 in. carries a central concentrated load of 2,000 lbs. Neglecting the weight of the beam the reactions at each support in this case will be equal to 1,000 lbs. The bending tendency is caused by the load pushing downward, while the reaction resists the downward action through the medium of the beam. The tendency is therefore to bend the beam as shown by dotted lines, the fulcrum being at the load point. The tendency to bend is equal to the amount of the reaction multiplied by its distance from the fulcrum. In this example therefore the bending tendency is 1,000 lbs. × 60 in., which equals 60,000 in.-lbs., and this is the value of the bending moment. This is the maximum bending moment, as the point lettered *A* on the diagram is the centre of the span, and the tendency will be less if a position nearer to the support is taken.

In *Fig.* 732 another point, marked *B*, is shown, only 30 in. from the support ; the tendency to bend here is indicated by dotted lines, and the leverage of the reaction is obviously less than the example in *Fig.* 731. The bending moment at *B* equals the reaction, which is still 1,000 lbs. multiplied by the distance to *B* which is 30 in.; therefore the value is 1,000 lbs. × 30 in., which equals 30,000 in.-lbs. It will be seen that the bending moment at *B* is only one-half the amount at *A*, and this shows that the bending moment gradually diminishes from the centre to the support at each end. This can be proved by taking a large number of points in the length of the beam and calculating the bending moment in accordance with the above method; it will be found that the variation in the moment with a loading as shown is directly proportional to the distance of the point selected from the support. The bending moment at the support is nil, the maximum moment is at the centre, and the value of the moment at any intermediate point can therefore be shown graphically by setting out the span of the beam to scale, and setting up the maximum moment to scale at the centre of a horizontal line joining the two supports, as shown in *Fig.* 733. The top of the line representing this maximum bending moment is then joined to the points where the horizontal lines meet the supports. This gives a triangle indicated by shaded lines, and the length

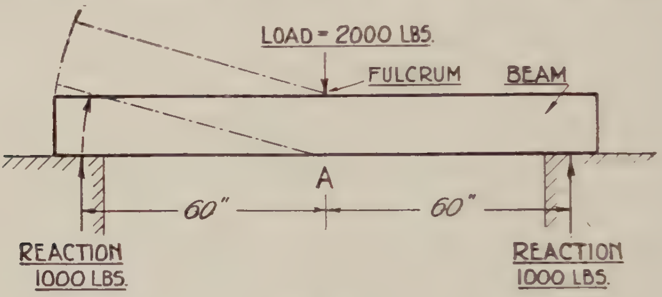

Fig. 731.

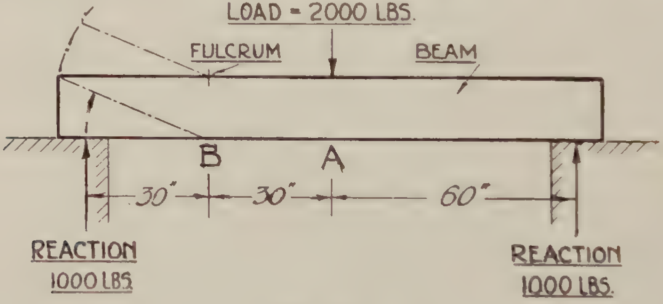

Fig. 732.

of the vertical line inside the triangle at any point indicates the value of the bending moment at that point to the same scale as that used in setting up the value of the maximum bending moment.

For example, the bending moment at *A* in *Fig.* 733 is 60,000 in.-lbs., and if the scale used in setting up the bending moment diagram is, say, 10,000 in.-lbs. to 1 in., then the length of the line *AE* in *Fig.* 733 will equal 6 in., and the length of the line *BF* will be 3 in., which at 10,000 in.-lbs. to the inch gives a value of 30,000 in.-lbs., as previously calculated.

The beam must be designed in accordance with the bending moment that has to be overcome. The value of the beam to resist the bending moment is known as the " moment of resistance," and therefore the moment of resistance must always equal the bending moment.

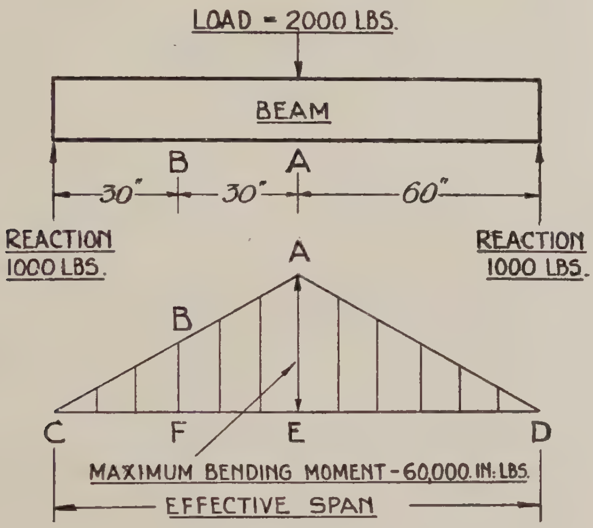

Fig. 733.

It is an elementary principle of statics that once a body such as a beam has ceased to alter its shape after the application of a load, the body may be regarded as rigid and is then kept in equilibrium by the combined actions of the external loads, including its own weight, and the reactions or supporting forces supplied by the columns or walls.

In *Fig.* 734 is shown a beam supported along all its length by a bench, and with vertical lines such as *XY* drawn on it. If the beam is now placed to span between the two supports and a load is applied the lines *XY*, X_1Y_1, etc., will be no longer parallel and vertical. The distance *XX* (*Fig.* 735) will now be less than YY_1 but the length ZZ_1 will remain unaltered. XX_1 is shortened and therefore must be in a state of compression strain. Similarly YY_1 is submitted to tensile strain. The length of ZZ_1 is unaltered and so there is no compression or tension along this line. The surface ZZ_1 is called the neutral plane of the beam and its intersection with any cross-section is the neutral axis of the section. Clearly the top and bottom fibres of the beam are more strained than those nearer the neutral axis, the strain being proportional to the distance of each fibre from the neutral axis. The compressive and tensile forces called into play above and below the neutral axis at any cross-section are those which are required to balance the external loads.

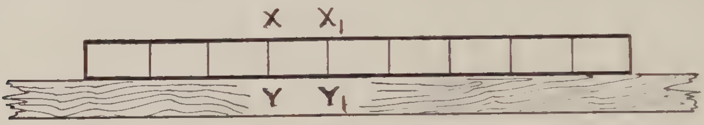

Fig. 734.

If a portion of a beam such as that shown in *Fig.* 736 be cut off from the remainder and loaded with weights W_1, W_2 and W_3, the internal forces exerted at the left-hand end by the remainder of the beam must be balanced by the external forces W_1, W_2, W_3 and R. The upward force S is the shearing force at the section. Since all the external loads are vertical, the resultant of the internal forces on the section cannot have any component in the horizontal direction—in other words, the tensile forces on the section balance the compressions.

In order that a rigid body may be at rest the sum of the forces acting on it in both of two rectangular directions must be zero and the sum of the moments of all the external forces about any point must be zero. If the first conditions are not fulfilled the body will obviously move in the direction in which the forces are not balanced. If the last is not true, the body will spin round. In the case of the portion of the beam considered, the moments of all the external forces must balance the moment of the internal forces about the same point. The sum of the moments of the external forces, acting on the portion, about any point is the bending moment at the point on the beam and is denoted by the letter M.

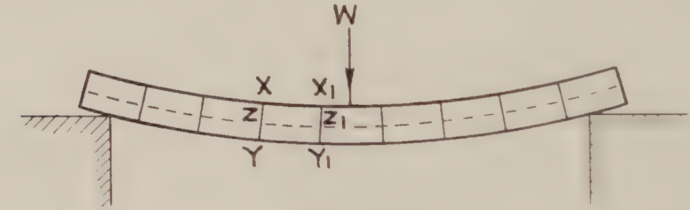

Fig. 735.

If the cross-section is considered as made up from a large number of fibres and if the cross-sectional area of one of these be a and its distance from the neutral axis y the unit stress on it will be proportional to y and may be denoted by cy. The force acting on the fibre is therefore equal to cya and the moment of this force about the neutral axis is $cya \times y = cy^2a$. The sum of the quantities y^2a taken for all the fibres is called the moment of inertia of the section about the neutral axis and denoted by I. Now $cI = M$. Therefore the stress f at a point distant y from the neutral axis is $f = \frac{My}{I}$ which is greatest at the top and bottom fibres, and if the working stresses of the material are known the formula above will give the bending moment which can be imposed on the beam without exceeding the safe stresses.

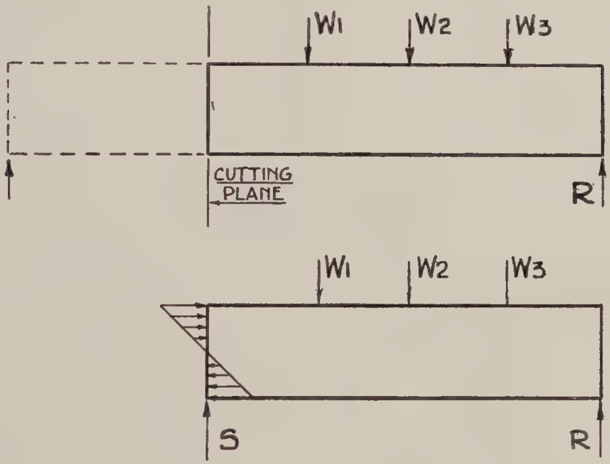

Fig. 736.

In reinforced concrete the bulk of the structure will be composed of concrete which provides the resistance to compression. The allowance generally made for concrete in compression is 600 lbs. per sq. in., and this is known as the "safe working stress." The Regulations of the London County Council require that concrete composed of 1 part of Portland cement, 2 parts of sand, and 4 parts of coarse material shall have an ultimate compressive resistance of at least 2,400 lbs. per sq. in. four months after mixing, and that ultimate compressive resistance one month after mixing shall not be less than 1,600 lbs. per sq. in. with a factor of safety of four. The allowable working stress on mild steel in tension is 16,000 lbs. per sq. in.

Relative Economy of Concrete and Steel in Compression and Tension

Assuming that the working stress on concrete in compression is 600 lbs. per sq. in., that concrete in place costs £3 per cu. yd. (or 2*s.* 2*d.* per cu. ft.), and that steel bent and fixed costs 2*d.* per lb., a comparison of the carrying capacities of concrete and steel in compression may be arrived at as follows. Steel weighs 480 lbs. per cu. ft., therefore 1 cu. ft. in position costs 960 pence, or thirty-seven times as much as the same volume of concrete. In other words, for the same length of column, steel costs thirty-seven times as much as concrete of the same cross-section. However, steel can carry 16,000 lbs. per sq. in. in compression, or twenty-six times as much as concrete. Therefore the cost of a given resistance to compression is $\frac{37}{26}$, or 1·4 times more expensive using steel than using concrete.

In tension concrete can only carry a safe stress of 50 lbs. per sq. in., whereas steel is capable of taking 16,000 lbs. per sq. in., or three hundred and twenty times the safe load on concrete. If steel, as before, costs thirty-seven times as much per unit volume, it is more economical for resisting tension than concrete in the ratio of $\frac{320}{37}$ to 1, or 8·7 to 1.

Whatever the relative costs of concrete and steel within the limits found in practice, the same principle holds that concrete is economic in compression and steel in tension.

Reinforcement

Steel rods are introduced in the concrete to provide the necessary resistance to tension, as concrete is deficient in this resistance. In reinforced concrete design the value of concrete in tension is neglected entirely, and no allowance is made for its resistance. Steel reinforcement may also be used to increase the resistance to compression when the amount of concrete that can be conveniently used is limited, as in the case of a small beam to carry a heavy load, or in the case of columns or piers. The resistance to compression offered by steel is the same as that in tension, or, in other words, it requires the same weight to crush short lengths as to tear them. When steel is used in conjunction with concrete to resist compression, the working stress is limited to a value which has a definite relation to the stress on the concrete.

Reinforced Concrete Beams

Singly Reinforced Beams.– An example of a singly-reinforced concrete beam of rectangular shape is shown in *Fig.* 737. It will be seen that the total depth is greater than the "effective" depth. The depth of the beam is one of the factors that affect the resistance, and when making the calculations the designer works to a fraction of an inch in order to produce an economical beam. The concrete below the neutral axis is neglected in design, and the depth used by the designer is the distance from the top of the beam to the centre of the reinforcement; the concrete below this is provided as protection only to the steel, and does not add to the resisting power of the beam when supporting a load. In addition to the main steel reinforcement shown in *Fig.* 737 it will be noticed that stirrups are indicated, and these are provided to resist the shear and to anchor the main rods to the concrete in the top portion of the beam.

The accurate placing of the tensile steel at the correct distance from the top surface of the beam is very essential in all reinforced concrete work. Failure to place the steel carefully as shown on the drawings may render the most careful calculations and designs useless and may cause serious overstressing of parts of the structure.

When a singly-reinforced concrete beam is designed in an economical manner to carry an ordinary distributed load, and the designer is not limited to depth and width, the concrete provided will usually be sufficient to give the necessary resistance to shear, and no stirrups will be required according to the calculations. Some stirrups should always be inserted in a beam; the extra cost is small and the load-carrying capacity of the beam is greatly increased by using them.

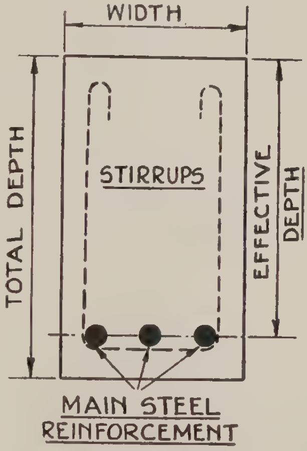

Fig. 737.

Doubly-Reinforced Beams.—In many cases the designer is unable to provide a satisfactory singly-reinforced concrete beam owing to the magnitude of the loads, and the amount of concrete necessary would result in a beam of excessive size. To reduce the amount of concrete and keep the beam within practical limits of size resistance to compression is provided by the concrete above the neutral axis assisted by some reinforcement in the compression area. The beam is then reinforced in both the bottom and top surfaces, and is known as a doubly-reinforced beam. The percentage of steel employed is greater than that necessary with a singly-reinforced beam, and as the steel is the expensive material the doubly-reinforced type is not economical.

In such beams it is necessary to anchor the compression steel in position, and sufficient stirrups must be provided for this purpose. The Regulations of the London County Council state that where the steel in compression is stressed to 16,000 lbs. per sq. in. it must be secured by anchors passing round or hooked over both the compressive and tensile reinforcement, and these anchors must not be spaced more than 6 in. apart centre to centre. The anchors are required both vertically and laterally, and this means a considerable number of links throughout the length, which adds to the cost of the work and also makes the steel-fixing more costly.

Tee-Beams.—The third type of beam used in reinforced concrete design is that known as the tee-beam, so-called on account of the shape of its cross-section. It is difficult to provide sufficient resistance to compression in the ordinary type of rectangular beam where heavy loads have to be carried, and in order to overcome this difficulty the beam is designed as a tee-section with a wide flange to give sufficient concrete in the top part of the beam, as shown in *Fig.* 738. The top or compression flange is much wider than the main beam or rib. The flange is provided by the floor slab between the beam itself and the adjoining ones. The rib contains the tensile reinforcement. The width of the slab that may be considered to act as the flange of the tee-beam is limited by the Regulations of the London County Council, and must not exceed any of the following:

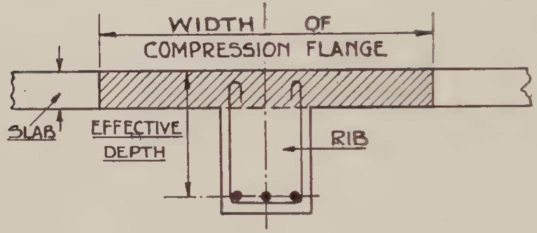

Fig. 738.

(1) One quarter of the effective span of the tee-beam;
(2) The distance between the centres of the beams; or
(3) Twelve times the thickness of the slab.

If a floor is constructed with beams having an effective span of 20 ft. and spaced at 6 ft. centres, while the thickness of the floor slab is 6 in., then the width of the flange must not exceed (1) one quarter of 20 ft. which equals 5 ft., or 60 in., (2) the distance between the centres of the beams, which is 6 ft. or 72 in., or (3) twelve times the thickness of the slab which equals 6 in. × 12 in. = 72 in. As the least of these three factors is the first mentioned this fixes the limit, and in this case the flange considered in the calculations must not be wider than 60 in.

When the neutral axis occurs in the rib itself the area of the concrete between the underside of the slab and the axis is so small, and the value so limited, on account of its nearness to the axis, that its resistance is almost negligible, and for all practical purposes it may be considered that the whole of the compression is taken by the flange. The reinforcement in the slab which is at right angles to the length of the beam must be carried right across the full width of the portion that is designed to act as a flange to the beam.

Fixed and Supported Beams.—Beams and slabs are divided into different types, as follows:

(1) Supported only at both ends;
(2) Fixed at both ends;
(3) Supported at one end and fixed at the other; and
(4) Continuous at both ends.

These types are distinct from the cantilever or bracket, which is fixed at one end only. Beams and slabs continuous over several spans are somewhat similar to those having fixed ends, because the ends of each span will be held in position by the adjoining bay and they are not therefore free to move.

Supported Ends.—The condition when the ends are supported only is shown in *Fig.* 739 where a beam is indicated carrying a concentrated central load. The tendency for the load to cause deflection is shown in an exaggerated manner, and it will be seen that the ends of the beam are free to move so that the whole beam is curved with the whole of the top part in compression and the whole of the lower part in tension. This condition will apply to beams and slabs only where the ends are supported; the condition of loading, whether concentrated or distributed, will not make any difference in the nature of the stress but only in the value.

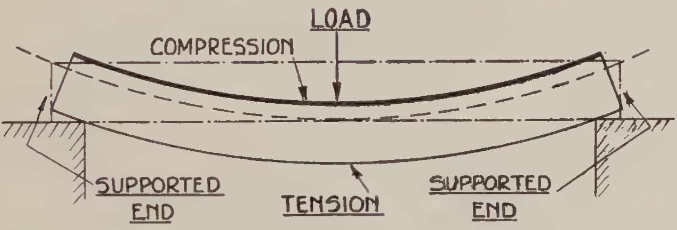

Fig. 739.

Fixed Ends.—If the ends of the beam are held firmly in position, then the beam is unable to bend in one simple curve under the action of the load, and the tendency is to take the shape shown in an exaggerated manner in *Fig.* 740. In this diagram both ends are fixed and a portion of the beam at each end acts as a cantilever with the top surface tending to stretch and the bottom surface tending to contract, while the central portion acts as a simply supported beam between the two cantilever portions. The fixing of the ends therefore results in tension and compression on the top surface (viz., tension at the ends and compression in the centre portion), and the reverse stresses on the bottom surface (viz., compression at the ends and tension in the centre). In the diagram the portion in compression is shown by a thick line, and the portion in tension by a thin line.

In such beams the stress changes in character at some point in the length of the beam. This point is called "the point of contraflexure." The position of this point depends on the type of load, but for all practical purposes it can be taken as one-fourth of the clear span from each end. This is shown in the diagram as $\frac{1}{4}$ L, when L equals the span, and the point of contraflexure is indicated by B. It will be realised that this change of stress is of the greatest importance, because the reinforcement must be placed in the tension area of the beam, and therefore in the beam shown in *Fig.* 740 the rods must be placed near the upper surface between the points A and B, while they are required near the lower surface between the two points marked B. In order to arrange this, some of the rods are cranked at the points of contraflexure as shown in the lower diagram in *Fig.* 740.

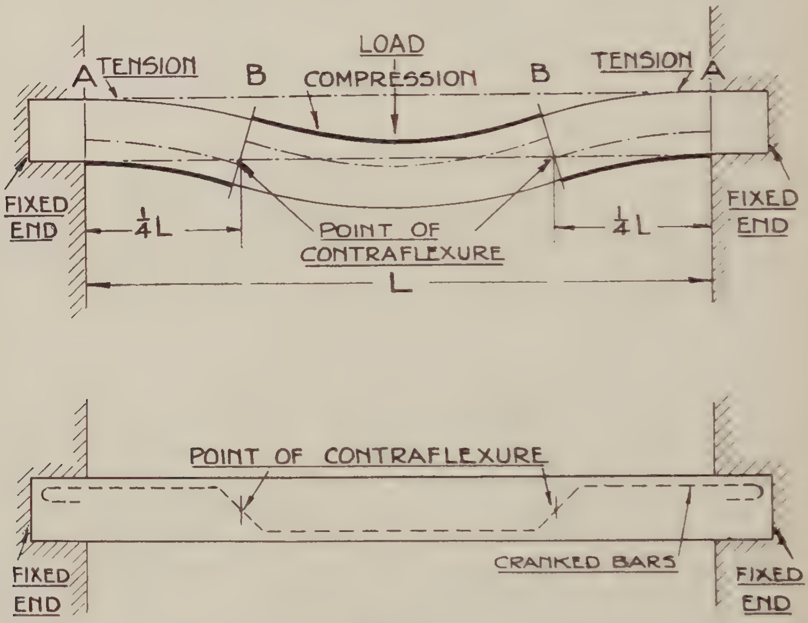
LOAD
A
TENSION
B
COMPRESSION
B
TENSION
A
FIXED END
¼L
POINT OF CONTRAFLEXURE
¼L
FIXED END
L
POINT OF CONTRAFLEXURE
CRANKED BARS
FIXED END
FIXED END

Fig. 740.

The fixing of the ends reduces the maximum stresses in the beam because it has an effect equivalent to reducing the span, and is therefore adopted in practice whenever possible.

Continuous Beams.—In reinforced concrete floors it is a frequent occurrence to find beams which are continuous over several spans. In this case the beam between any two columns can be considered as restrained at the ends and calculations made accordingly. The end span will generally be taken as supported at one end when it is resting on a wall, and the other end will be considered as continuous. The shape of a beam which is continuous over several spans is shown in *Fig.* 741; the thick lines indicate the portions in compression and the thin lines the parts in tension. It will be seen that the stress is alternately compression and tension in both top and bottom surfaces owing to the cantilever action on each side of the column support.

Continuous Tee-Beams.—In the case of tee-beams it is not advantageous to fix the ends, because it is necessary to keep the whole length of the upper surface of the beam in compression to allow the slab forming the top flange to take the stress. If the ends of a tee-beam are fixed or restrained and compression has to be provided for in the lower surface of the beam at the ends, it is necessary to increase the area of either the concrete or of the steel, and in some cases both must be added to. Increasing the steel area will not be economical owing to the low limit of stress that can be allowed on the steel in compression, and it is better to increase the concrete if this is practicable.

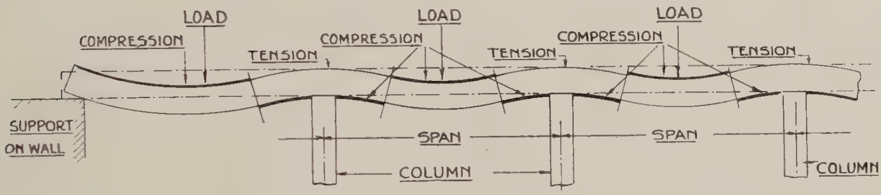

Fig. 741.

Reinforced Concrete Columns

Columns are called upon to support the ends of beams and provide the reaction necessary to counteract the load and in the ordinary way they are subject to direct compression. Columns can be divided into (*a*) short columns and (*b*) long columns according to the ratio between the height of the column and its diameter. If the column is rectangular or of irregular shape, then the width of the least dimension must be taken in computing the ratio.

If a reinforced concrete column is 12 ft. high and 12 in. square, then the ratio is 144 in. divided by 12 in., which equals 12; whereas a column 12 ft. high and 12 in. by 6 in. in section has a ratio of 144 divided by 6, which equals 24. If the rectangular column were increased to 14 in. by 6 in. the ratio would still be 24, but if the size were changed to 9 in. square the ratio would be altered to $\frac{144}{9} = 16$. The lower the ratio the stiffer the column and the greater the load per sq. in. that can be safely carried. The full working stress of 600 lbs. per sq. in. on the concrete is only permitted when the ratio for a square column does not exceed 15, and in the case of a round column when the ratio does not exceed 12.

The term "short-column" does not necessarily mean it is a low one in actual height, but that the ratio is low; thus a column 30 ft. long will still be classified as a short one if the diameter is made as much as 30 in.

The stiffness of a column is affected by the condition of the ends as regards the fixing. If the ends are rigidly held in position it will be less flexible and therefore able to offer more resistance to the weight which is tending to cause it to buckle than when the ends are free to move. In the Regulations of the London County Council it is stated that a pillar or strut shall be deemed to have fixed ends when the ends are sufficiently secured to other parts of the construction having such rigidity as will maintain the axis at the ends in its original position and direction under all loads less than the crippling load.

When the ends of a column are free to move the tendency is for the column to bend in one simple curve, as explained for beams that are supported at the ends, whereas the fixing of the ends means that the bending is restrained and the tendency to bend is reduced in a similar manner to that given in connection with beams having fixed ends.

There is one other point that must be mentioned as having a bearing on the design of columns, viz., the links or binding which are provided around the main vertical steel reinforcement. The links or binding are a definite factor in the strength of the column and the stress on the concrete may be safely increased to a certain extent where sufficient binding is provided. The Regulations of the London County Council state that the volume of the binding shall not be less than 0·5 per cent. of the volume of the hooped core. This amount is necessary to allow the concrete to develop the working compressive strength of 600 lbs. per sq. in., but if more binding is provided the working stress can be increased up to as much as 800 lbs. per sq. in. for an ordinary 1 : 2 : 4 mixture according to the ratio of the volume of binding to that of the concrete.

Concrete Core.—The concrete in a reinforced concrete column can be considered as consisting of two parts, (*a*) the core and (*b*) the protective covering. *Fig.* 742 shows the section of a typical column reinforced with four vertical rods and having an overall size of 15 in. by 15 in. The protective covering must be not less than 1½ in. thick or less than the diameter of the vertical steel rods, and assuming that these rods are not more than 1¼ in. diameter, the covering will be 1½ in. thick outside the rods, giving an internal core of 12 in. by 12 in. The covering is neglected in the calculations as regards the ratio of diameter to height and also in the area of concrete to resist the load. The "effective" diameter which is the diameter of the hooped core and the area of the concrete within the hooped core only are considered.

In a short column which has the minimum permissible binding the concrete can be calculated to resist safely a compression of 600 lbs. per sq. in., and in the example given in *Fig.* 742 therefore the safe load is 12 in. × 12 in. × 600 lbs. = 86,400 lbs., plus the value of the resistance of the steel.

It may be considered that the concrete outside the vertical rods will also be capable of carrying some of the load, but it will be clear that in case of fire this covering is liable to crack and possibly break away; in addition the binding around the core increases the resistance of the concrete as it restrains the material, and it would not be economical to restrict the safe load per sq. in. to the comparatively low limit of the concrete which is not hooped, especially as this would have the effect of reducing the working stress on the steel on compression.

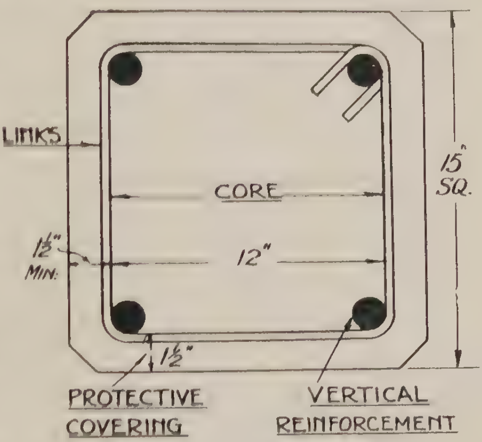

Fig. 742.

Vertical and Lateral Reinforcement.—In order to assist the concrete to support the load and avoid the necessity of providing very large columns, reinforcement is added in the form of vertical rods which extend through the full height of the column. These rods are placed as near to the outer surface as possible in order to get the maximum value out of the steel, because the material which is the greatest distance from the axis of the column will be of the most assistance in resisting bending.

When four vertical rods are used they are placed in the corners of the column, as shown in *Fig.* 742, but six, eight or any number may be adopted according to the requirements. In the case of circular or octagonal columns, where circular binding is used, at least six vertical rods must be employed and frequently eight are provided. As the steel rods are provided to resist compression and assist the concrete, the working stress is limited to fifteen times that on the concrete core; it is therefore not economical to design the columns with the maximum steel and the minimum concrete because the former cannot be stressed up to its full working strength without injury to the latter. The minimum steel permitted in the London County Council Regulations is 1 per cent. of the hooped core, and the diameter of the rods must not be less than ½ in. or greater than 2 in.

The spacing of the binding or links must not exceed six-tenths of the effective diameter of the column at any part of the length, while at the ends the pitch must not exceed three-tenths of the effective diameter for a length equal to one and a half times the effective diameter.

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